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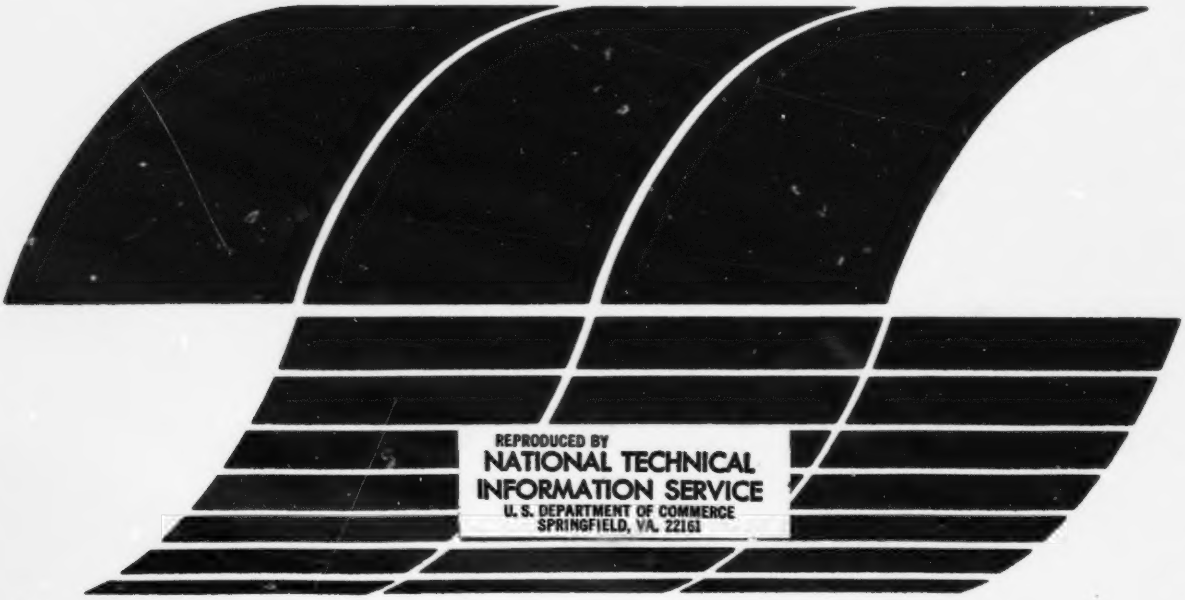

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Aerometric data were collected during 16 months in the vicinity of the coal-fired Clinch River Power Plant, located in the complex terrain of southwestern Virginia. Statistical analyses of SO_2, NO, and NO_x concentrations at eight fixed monitoring sites revealed significant diurnal and seasonal variations. Ridge sites showed maximum concentrations at night but without a well-defined diurnal pattern; valley sites showed a well-defined late morning maximum, hypothesized to be caused by plume fumigation. Cross-section pollutant and meteorological measurements made from a helicopter were analyzed to show the dimensions of the plume. Plume heights calculated from wind and temperature profiles and plume widths calculated from the standard deviation of wind direction produced improvements over standard estimates. The influence of terrain features on the shape and path of the plume is clearly shown when assessing the helicopter data and selected case studies of ground monitoring data. Parameters for a Gaussian plume model were modified in a stepwise manner by using site specific meteorological data. The study showed that the standard flat terrain model and modifications frequently used to represent complex terrain influences can be improved by judicious use of site-specific data. The Gaussian plume model can provide useful estimates of maximum concentrations, but it cannot generate reliable hour-by-hour concentrations due to influences imposed by a complex terrain setting. The data obtained for the Clinch River site should be useful in further diagnosis and model testing of plume behavior in complex terrain.

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Data Analysis and Characterization of Plume Behavior

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ABSTRACT

Data collected during a 16-month field program conducted near the Clinch River Steam Plant in western Virginia were analyzed to characterize the behavior of a power plant plume in complex terrain. Onsite measurements and synoptic scale meteorological data are summarized for 31 periods of significant SO_2 measurements and similar meteorological conditions.

Statistical analyses of SO_2, NO and NO_X concentrations at fixed monitoring sites and in one of the two plant stacks revealed significant diurnal and seasonal variations. Ridge sites showed maximum concentrations at night but without a well defined diurnal pattern; valley sites showed a well defined late morning maximum hypothesized to be caused by plume fumigation. Cross-section pollutant and meteorological measurements made from a helicopter during July were analyzed to show the dimension and height of the plume as a function of distance from the plant. Plume heights calculated from wind and temperature profiles and plume widths calculated from the standard deviation of wind direction produced improvements over standard estimates. The influence of terrain features on the shape and path of the plume is clearly shown when assessing the helicopter data and selected case studies of ground monitoring data. Uncertainties in hourly measurements of sulfate due to laboratory assessment accuracy, random natural deposition, duration of ambient exposure, and other unexplained factors are undesirably large; however, there is evidence in the measurements of contributions from both the nearby plant and more distant sources.

Parameters for a Gaussian plume model were modified on a stepwise basis of considering the impact of site specific meteorological and terrain data. The study showed that the standard flat terrain model and modifications frequently used to represent complex terrain influences can be improved by using data available for the Clinch River site. The Gaussian plume model can provide useful estimates of maximum concentrations to be expected, but it can not represent on an hour-to-hour basis the influences of the complicated flow found in a complex terrain setting. The data obtained for the Clinch River site provide a useful record of the physical behavior of a power plant plume in complex terrain and will be useful in testing hypotheses of plume behavior and in diagnosing plume behavior.

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SECTION 1

INTRODUCTION

In this study we have analyzed aerometric data collected in the vicinity of a coal-fired power plant located in the complex terrain of southwestern Virginia. This report describes the data used in these analyses, the types of analyses performed and relationships that have been identified between terrain characteristics, meteorological conditions, plant emissions and the resulting ground-level pollutant concentrations. This analytical work represents the third phase of a three-phase study of the behavior of power plant plumes in complex terrain. The first phase (Koch et al. 1977) consisted of a literature review of the current state of knowledge of plume behavior in complex terrain with respect to both the transport and diffusion processes and the pollutant transformation and removal mechanisms. The second phase (Koch et al. 1979) consisted of an aerometric field study to collect data related to plume behavior in complex terrain in the vicinity of Clinch River Steam Plant near Carbo, Virginia. Sixteen months of ground-level pollutant concentration data and meteorological measurements were gathered in an eight-station monitoring network. The fixed stations were supplemented by upper-air meteorological observations, stack emission measurements, and pollutant monitoring from a mobile van and a helicopter.

The study as a whole was undertaken due to the generally recognized lack of complete understanding of plume behavior in complex terrain. Phase II provided a set of SO_2, sulfate, NO, NO_2, and meteorological data from which conclusions can be ascertained concerning pollutant transport, diffusion and transformation in mountainous terrain and from which improved dispersion modeling techniques can be developed. Accurate prediction of air quality levels in complex terrain is becoming more critically important than ever before as major power plants and industrial sources plan to locate in these regions. For each new major pollution source studies must be performed to predict the potential air quality impact of the operation of these sources for the purposes of showing compliance with Prevention of Significant Deterioration regulations. Coal-fired electric power plants are major sources of SO_2 and NO. Sulfur dioxide and sulfate, which is formed from SO_2 in the atmosphere, are recognized to produce adverse health effects. Also, NO is converted in the atmosphere to NO_2, which has been determined to be a health hazard.

The Phase III analyses include (1) the identification of data periods containing significant plume impact; (2) statistical summaries of emissions, ground-level pollutant concentrations, and meteorological data; (3) statistical summaries of relationships between concentration and meteorological data; (4) the analysis of plume cross sections observed by helicopter; (5) the development of vertical profiles of wind speed, wind direction, and temperature; (6) use of the vertical wind and temperature profiles for estimating plume heights; (7) an analysis of observed sulfate data in relation to SO_2 concentrations and meteorology; (8) an analysis of dispersion model estimates of SO_2 concentrations in relation to measured values; and (9) a detailed examination of the causes for individual cases of high SO_2 concentrations.

The data from the Phase II field study were reduced, edited and placed on a magnetic tape for distribution. The tape contains 34 files of data which include 8 fixed-station files, 1 sulfate file, 1 upper-air meteorological data file, 7 ground-mobile data files, 16 helicopter data files and 1 plant operating data file. A copy of this tape is available from the National Technical Information Service. The data formats are described in the Phase II report (Koch et al. 1979). The Phase III analyses have been based on these data sets along with additional information contained in field notes and logs, daily weather maps, and raw data files.

SECTION 2

SUMMARY AND CONCLUSIONS

Field observations collected in the vicinity of the Clinch River Steam Plant in southwest Virginia for a period of about a year were analyzed to determine relationships which characterize the behavior of the plume in complex terrain. The data include measurements from eight fixed monitoring stations, a mobile van, one of the two plant stacks, a helicopter, and balloon soundings. The following conclusions have been drawn from the data analysis:

- There are 31 significant periods of 2 to 20 days' duration in which the meteorological conditions are consistent and during which high SO_2 and NO_x concentrations indicated that the plant plume was observed.

- The significant data periods include 16 periods with locally dominated flow patterns and 15 periods with synoptically dominated flow. All but one period had a majority of the hours having stable conditions as defined by the bulk Richardson number.

- Valley stations have a diurnal pattern of concentration with a maximum in the morning daylight hours. This differs from the diurnal patterns of ridge stations which do not have well defined maxima. The valley maximum is probably due to fumigation of the plant plume which is trapped in nocturnal valley inversion layer.

- Ridge stations are exposed to higher maximum 1-hour concentrations than are valley stations. The maximum concentrations at ridge stations generally occur at night. This differs from valley stations which have maximum concentrations during the day.

- The mobile van was capable of recording plume impact with greater frequency than did any of the fixed monitoring stations. The van measured hourly average SO_2 concentrations greater than 20 ppb approximately 50 percent of the time, while the fixed station (Tower) with the greatest number of significant readings had concentrations greater than 20 ppb only 16.5% of the time. Higher SO_2 concentrations were recorded by the van than by any of the fixed stations. This result indicates that the van was under the plume centerline more often than were any of the fixed stations.

- The mobile van was also useful in providing data for the study of the NO/NO_2 ratio as a function of distance from the plant. This ratio had a mean value of 5.6 for measurements within 0.5 km of the plant and was found to decrease to approximately 0.8 at distances of 3 km to 15 km from the plant.

- The plume cross section for a period of an hour as observed by helicopter agrees well with dimensions indicated by variations in wind direction and computed plume paths using 2-minute winds. These results indicate that wind observations taken on a 30 m tower at a ground elevation near the height of the plume are useful in defining the dimensions of the plume (i.e., during daylight hours when the flow at the observation height is well mixed to ground level).

- The horizontal dispersion parameter σ_y, as observed by the helicopter is well represented by Pasquill's suggestion of:

  $$\sigma_y = \sigma_A \times f(x).$$

  The mean ratio (measured σ_y/Pasquill σ_y) was 1.16 over 17 cases. The former Pasquill-Turner representation underestimates the observations. The mean ratio (measured σ_y/Pasquill Turner σ_y) was 1.47 over 24 cases of mostly neutral to unstable conditions.

- The helicopter cross sections were also useful in examining the behavior of the plume approaching a ridge. The plume height above the terrain was reduced by 63 percent of the terrain elevation increase in a stable atmosphere case and by 52 and 71 percent in two unstable cases.

- When the plume trajectory is deflected by terrain features, influenced by a valley flow regime, or in a flow separation in which low level winds are subject to different influences than winds at plume height which are above a low level inversion, the plume trajectory cannot be represented by a uniform wind flow model. Based on a test sample of 46 days and nights, the complex flow exists 56 percent of the time.

- Plume height estimates are significantly improved by a methodology using wind and temperature profiles, rather than a methodology based on standard stability conditions. In a comparison of the plume height estimates with the plume centers of mass determined from 23 helicopter plume cross sections the mean absolute error was reduced from 321 m to 143 m by the use of the method employing the wind and temperature profiles instead of the standard stability classes.

- A major problem with hourly sulfate measurements is the fact that there is a large amount of inadvertent deposition on the filters when the sampling blower is not operating. Future measurements must be directed toward better control of this interference. The data collected in this study suggests that the nearby power plant makes some, but probably not the major, contribution to sulfate concentrations in the vicinity of the plant.

- The simple Gaussian plume model, when applied using site-specific meteorological data to estimate plume dimensions (e.g., through standard deviation of wind azimuth observations) and local terrain heights to estimate plume height above ground, can significantly improve SO_2 concentrations for estimates made with a flat terrain model and standard Pasquill-Gifford dispersion parameters. The use of terrain adjustment factors such as are found in the CRSTER and VALLEY models were found to not improve the standard flat terrain estimates.

- The simple Gaussian model cannot be expected to give better results on a case by case (specific hour basis) by improved model parameter estimates than were found in this study, because it cannot be managed with the complex flow pattern which is present at least 50 percent of the time at the Clinch River plant site. The data contains numerous examples which clearly indicate the presence of a complex flow pattern. However, the Gaussian plume model provides valuable guidance regarding what the maximum concentrations over a long period of time can be expected to be.

- The degree of accuracy found by applying the Gaussian model with site specific data to central Pennsylvania sites was found to be better than the accuracy found at the Clinch River site. Over the stations considered the average model/observed ratio for the highest SO_2 values was 1.23 at Chestnut Ridge Monitoring Network compared with 1.58 at the Clinch River Network.

- The data collected from the Clinch River plant site provides a valuable source of data for testing hypotheses regarding the physical and chemical behavior of power plant plumes in complex terrain. Among the unique data available are hourly wind and temperature measurements from eight sites for a period of a year, NO and NO_x measurements at six sites for a period of ayear, several hundred hourly sulfate measurements, and nearly daily temperature and wind profiles from balloon observations. In addition, there are a large number of other observations which are similar to data from other sites including a year of SO_2 measurements at eight monitoring sites; 24 hourly cross sections of SO_2, NO, NO_x and O_3 from helicopter measurements; observations from a mobile van; and hourly stack emission measurements of NO and SO_2.

SECTION 3

DESCRIPTION OF THE CLINCH RIVER POWER PLANT, TERRAIN AND MONITORING NETWORK

The site chosen for the aerometric field study was the vicinity of the Clinch River Steam Plant in Carbo, Virginia, located approximately 200 km west-southwest of Roanoke. This site was chosen because:

- It is located in a nonurban, mountainous, area, isolated from other major sources of SO_2.
- Terrain in the vicinity of the plant exceeds 1-1/2 times the stack height.
- An adequate network of roads existed to facilitate mobile sampling and access to fixed monitoring sites.
- The power company was willing to cooperate.

PLANT DESCRIPTION

The Clinch River Steam Plant has a total generating capacity of 712 MW, fired by low-sulfur coal in each of three boilers. Exhaust gases are emitted through two stacks, 46 m apart, each 138 m high. Stack 1 with a diameter of 4.76 m serves boilers 1 and 2, while Stack 2, with a diameter of 3.81 m serves boiler number 3. The boiler water is cooled through the use of five mechanical draft cooling towers, each 18.6 m high.

TERRAIN

The location of the plant in southwestern Virginia is shown in Figure 1. The details of the surrounding terrain, including the fixed monitoring site locations are shown in Figure 2.

The terrain is generally characterized by a series of parallel ridges and valleys which run southwest to northeast. However, numerous pronounced short valleys run perpendicular or askew to the larger valleys, making a very irregular and complex layout of terrain. Although many terrain features are inaccessible, about half of the terrain is occupied by small farms and rural residences.

The plant elevation is 461 m, which puts the stacktops at just under 600 m. There are ridges exceeding 680 m (2200 ft) within 3 to 5 km of the plant in all quadrants of the compass. Elevations exceeding 870 m (2900 ft) occur within 8 km to the northwest and 14 km to the southwest. Clinch Mountain,

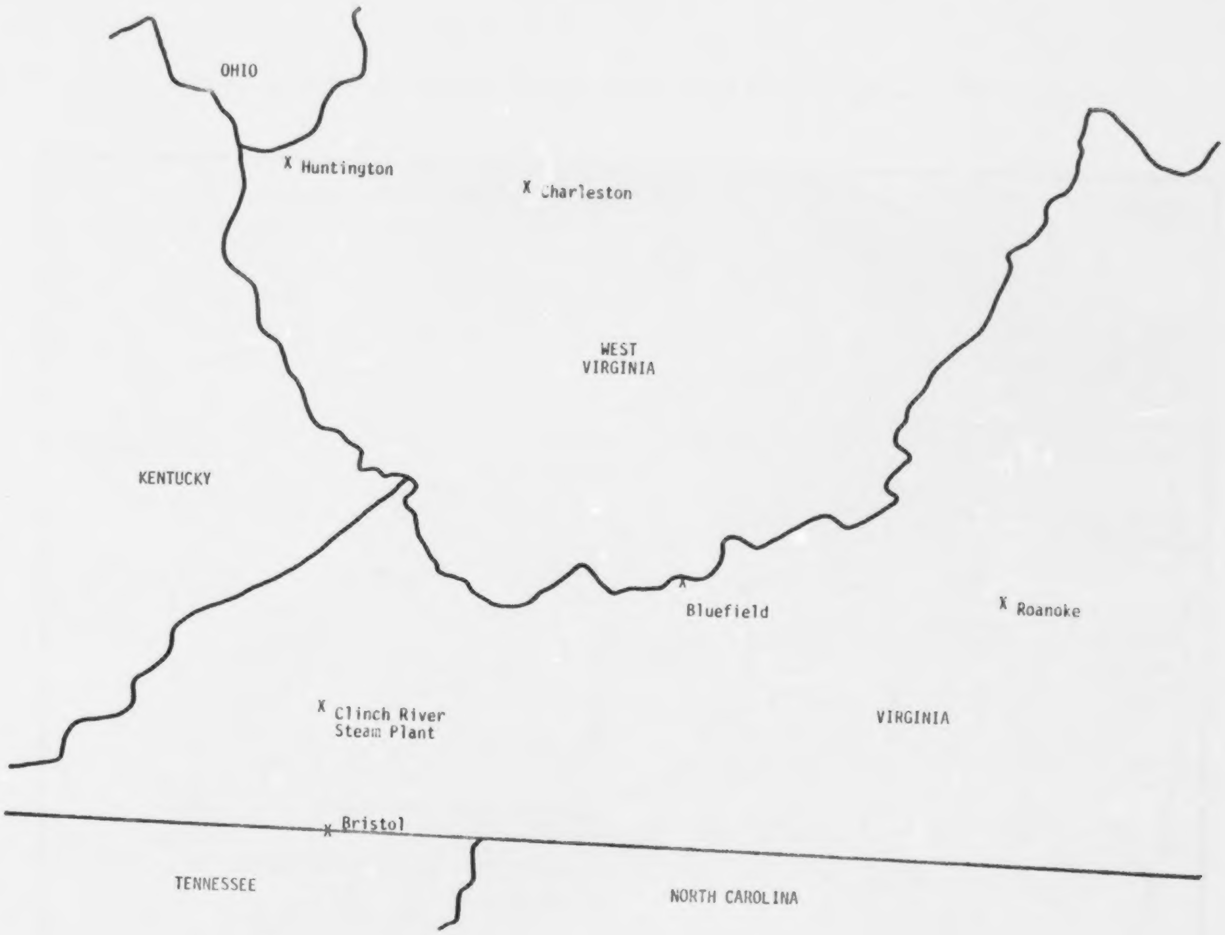
OHIO
X Huntington
X Charleston
WEST VIRGINIA
KENTUCKY
X Bluefield
X Roanoke
X Clinch River Steam Plant
VIRGINIA
X Bristol
TENNESSEE
NORTH CAROLINA

Figure 1. Location of the Clinch River Steam Plant.

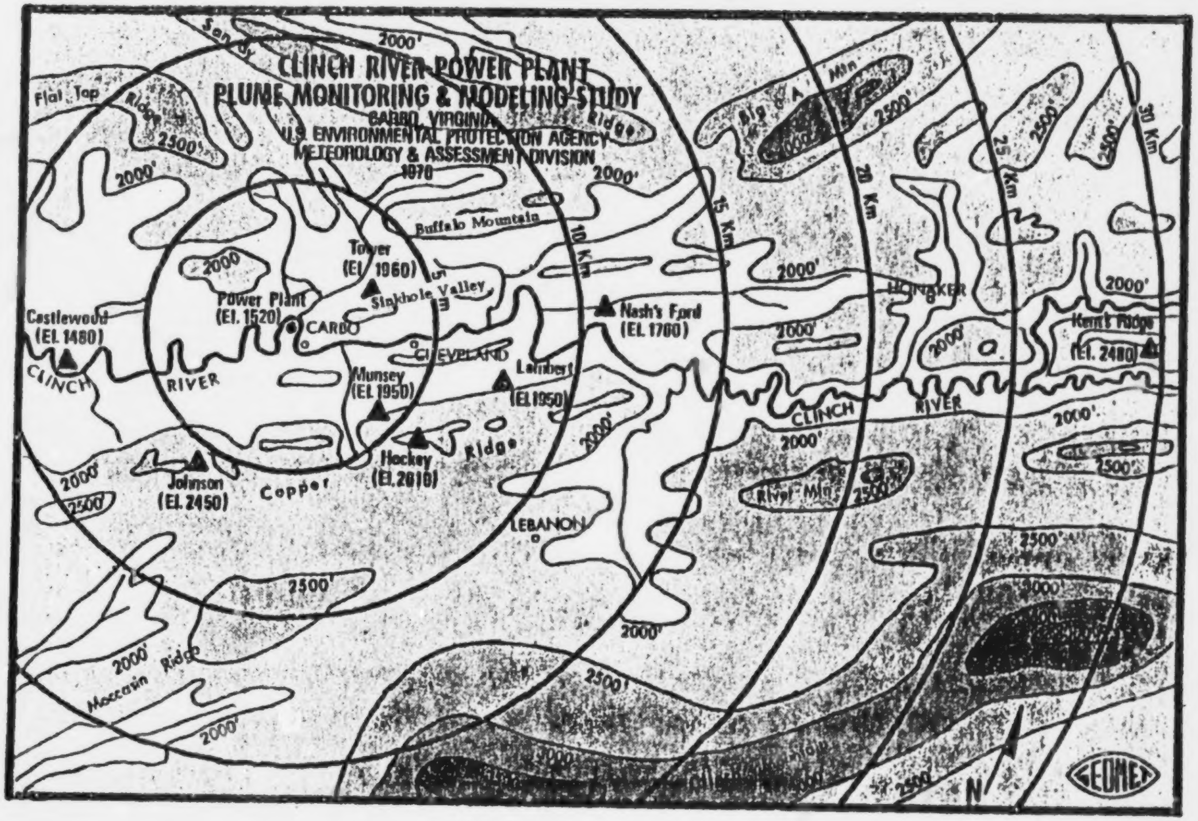
CLINCH RIVER POWER PLANT
PLUME MONITORING & MODELING STUDY
CARBO, VIRGINIA
U.S. ENVIRONMENTAL PROTECTION AGENCY
METEOROLOGY & ASSESSMENT DIVISION
1970
Flat Top Ridge
Sandy Ridge
Big A Mtn
Buffalo Mountain
Tower (El. 1960)
Sinkhole Valley
Power Plant (El. 1520)
CARBO
CLEVELAND
Castlewood (El. 1480)
CLINCH RIVER
Munsey (El. 1950)
Lambert (El. 1950)
Nash's Ford (El. 1700)
HONAKER
Kent's Ridge (El. 2480)
Hockey (El. 2810)
Johnson (El. 2450)
Copper Ridge
LEBANON
River Mtn
Moccasin Ridge
10 Km
15 Km
20 Km
25 Km
30 Km
2000'
2500'
3000'
N
GEOMET

Figure 2. Topographical features and fixed monitoring sites. Elevations are in feet above sea level.

located 14 km southeast of the plant, is the highest terrain in the area. It runs northeast-southwest for approximately 25 km and reaches elevations in excess of 1260 m (4200 ft,). Big A Mountain, located 20 km northeast of the plant rises to 1140 m (3,800 ft.). Flat Top Ridge, situated 8 km northwest of the plant, is oriented northeast-southwest and reaches elevations up to 915 m (3,000 ft.). The major pattern of ridges and valleys trending northeast-southwest is transected by many streams running northwest-southeast to form a truly complex terrain.

In the immediate vicinity of the plant (within 1 km) ridges extend to to 100 m above the top of the stacks. The highest elevations lie to the east-northeast and to the northwest. A pronounced ridge also extending 100 m above the stack is located approximately 2 km to the southeast. Flow over these nearby terrain features on windy days causes a pronounced downwash of the stack plumes. Further to the southeast is Copper Ridge, which exceeds the stack top elevation by 200 m. Buffalo Mountain, also reaching 200 m above the stack, is located 6 km to the northeast.

MONITORING NETWORK

The eight fixed monitoring station locations were selected to meet design criteria for climatology, local topography, existing roadways and utility services, and the ability to negotiate for the land on which to place the instrument shelter. Locations were selected using guidance from dispersion model calculations and representative climatological data. The characteristics of the selected sites are summarized in Table 1. Initially, only six stations were operated. The Lambert site was brought into operation on October 27, 1976, and the Johnson site became operational on November 15, 1976. The Castlewood station washed away in the flood of April 5, 1977, reducing the number of fixed monitoring sites to 7. The Lambert instrumentation was installed at Castlewood during July 1977.

At Site No. 1 (Tower) a 30 m tower was installed to measure winds at two levels and temperature at three levels. This site was 3.4 km to the northeast of the plant at an elevation of 585 m. The site was in open terrain and air flows in the region were unobstructed by vegetation or nearby terrain features. The nearest terrain feature was a ridge located 1 km to the south. This was the closest site to the power plant. It had an elevation of 124 m above the base of the plant.

Site No. 2 (Munsey) was located 4 km to the southeast of the power plant. It was approximately 1/3 of the way up the hillside from the valley floor to the Hockey site, located 200 m higher. The two sites are on about the same bearing from the plant and were used to resolve the characteristics of the plume perpendicular to the ridge on which these two sites were located.

Site No. 3 (Nash's Ford) was located approximately 11 km to the east of the power plant in the Clinch River Valley. The site was situated on a small plateau between the Clinch River and a small creek, and was representative of upvalley flows from the power plant due to thermodynamic effects and due to channeling of the wind.

TABLE 1. MONITORING SITE CHARACTERISTICS

Site Number	Site Name	Orientation from Power Plant		Site Elevation		Terrain Characteristics
		Direction	Distance (m)	MSL (m)	Above Plant Base (m)	
1	Tower	46°	3360	585	124	Plateau
2	Munsey	111°	4250	597	136	Valley Side
3	Nash's Ford	64°	10820	567	106	Plateau
4	Hockey	107°	5710	792	331	Ridge
5	Castlewood	238°	8280	451	-10	Valley
6	Kent's Ridge	68°	29870	756	295	Ridge
7	Johnson	191°	5760	719	258	Ridge
8	Lambert	82°	7560	597	136	Valley Side
9	Stack	--	0	461	0	Valley

Site No. 4 (Hockey) was located on a ridge (792 m msl) just above the Munsey site and on a line with Munsey and the power plant. This site was selected to observe the concentration characteristics of the power plant plume in relation to the ridgetop.

Site No. 5 (Castlewood) was located approximately 8 km west-southwest of the power plant. It was very close to the Clinch River; however, it had an unobstructed upvalley view so that winds from that direction would be characteristic of drainage flows if they were occurring. This site was about 10 m below the plant elevation. The station washed away in the flood of April 5, 1977.

Site No. 6 (Kent's Ridge) was located 30 km east-northeast of the power plant. This site was chosen for both its elevation and distance and was the most distant site from the Power Plant.

Site No. 7 (Johnson) site which was located south-southwest of the power plant on a ridge that runs from the west-southwest to the east-northeast. This is the same ridge line that Hockey was located on.

Site No. 8 (Lambert) was located approximately one-third of the way up the side of a valley. It was chosen to determine the plume characteristics in that valley. The instrumentation was moved to Castlewood in July 1977.

A stack monitor was located in the duct work at the base of the Unit 3 stack. The monitor was between the electrostatic precipitators and the base of the stack. Valid data was collected after December 1, 1976.

Table 2 summarizes the types of data that were available from each of the fixed stations. A mobile van monitored SO_2, NO_x, NO, and O_3 while moving under the plume and also at stationary locations within the footprint area of the plume on many days throughout the field program. A helicopter flew traverses through the plume during two 10-day periods also measuring SO_2, NO_x, NO, and O_3. The helicopter monitoring periods occurred in November 1976 and July 1977. The fixed-station meteorological data were supplemented by upper air wind and temperature data obtained by the use of pilot balloons with attached T-sondes. The National Weather Service surface and upper air analyses were received at the plant by facsimile circuit.

TABLE 2. SUMMARY OF MEASUREMENTS AT FIXED MONITORING SITES

	SO_2	NO_x	NO_2	NO	Temp (10m)	Temp $(T_4-T_{0.5})$	Temp $(T_{30}-T_{0.5})$	Wind Speed (10m)	Wind Direction (10m)	Wind Speed (30m)	Wind Direction (30m)	Standard Deviation of Wind Azimuth (10m)	Standard Deviation of Wind Elevation (10m)	Standard Deviation of Wind Azimuth (30m)	Standard Deviation of Wind Elevation (30m)	Relative Humidity	Total Particulate	UV Radiation	Precipitation
Tower	X	X	X	X	X*	X	X	X	X	X	X	X	X	X	X	X		X	X
Mussey	X	X	X	X	X			X	X			X							
Nashs	X	X	X	X	X			X	X			X					X		
Hockey	X	X	X	X	X			X	X	X	X	X		X			X		
Castle	X	X	X	X	X			X	X			X					X		
Kents	X	X	X	X	X			X	X			X					X		
Lambert	X							X	X			X							
Johnson	X							X	X			X					X		

* Temperature of Tower recorded at 4m

SECTION 4

DATA PERIOD ANALYSIS

In order to synthesize the data from the 16-month Clinch River field study in a form which can be used to identify periods of interest for future studies, the data were organized into cohesive periods based on observed characteristics of the airflow.

DATA ORGANIZATION

The data were organized through the compilation of 11 parameters on a daily basis over the entire monitoring period at the Clinch River Steam Plant. The following parameters were included in the data listing:

1. Predominant Airflow Influence--To determine airflow influence each day was divided into two 12-hour periods; daylight (0700 to 1800 local standard time) and nighttime (0100 to 0600 and 1900 to 2400 local standard time). Then, all the hourly fixed station wind directions, with the exception of Kents Ridge, were analyzed on a daily basis for both daylight and nighttime by summing the number of wind directions in eight 45° sectors (i.e., 0°-45°, 45°-90°, etc.). If the sector with the highest frequency consisted of more than 41 percent of the total cases, then the winds for that 12-hour period were designated as synoptically influenced; if less than 41 percent, the winds for that period were designated as locally influenced. The cutoff value of 41 percent was determined by noting that the mean percentage of observations in the prevailing wind direction sector over a sample group of days was 41 percent. Lacking any good guidelines, we decided that, if the frequency of the prevailing wind octant exceeded this mean frequency, the wind direction was relatively consistent in time and space and primarily synoptically influenced. This classification scheme resulted in four possible categories for a day:

   1. Synoptic daylight and night (S)

   2. Local daylight and night (L)

   3. Synoptic daylight, local night (SL)

   4. Local daylight, synoptic night (LS).

2. Fixed Stations Exhibiting Significant Concentrations--For each day the stations which had significant concentrations of SO_2 and NO_x were listed. The cutoffs for significant concentrations at each station were determined by assigning a significant concentration to the Tower site and using a log-linear decrease with distance from the plant to assign values to other

sites. The following relationships were used to determine significant concentrations of SO_2 and NO_x:

$$\frac{\ln(D_T)}{\ln(D_X)} \times 60 \text{ ppb} = \text{Significant } SO_2 \text{ Concentration at Station X.}$$

$$\frac{\ln(D_T)}{\ln(D_X)} \times 100 \text{ ppb} = \text{Significant } NO_x \text{ Concentration at Station X,}$$

where D_T is the distance from the plant to Tower, and

D_X is the distance from the plant to Station X

NO_x is total of NO_2 and NO concentrations.

This resulted in the following cutoffs of significant concentrations for each fixed station:

Station	SO_2 ppb	NO_X ppb
Tower	60	100
Castlewood	35	58
Hockey	41	68
Munsey	50	83
Lambert	36	--
Johnson	41	--
Kents	22	37
Nashs	31	52

3. Diurnal Variation in Vertical Temperature Difference - The daily range of vertical temperature differences measured over the interval 0.5 m to 30 m at the Tower site were categorized as small (range less than 2.0°c), medium (range from 2.0°C to 3.2°C) or large (range greater than 3.2°C). The categories were established by examining the distribution of the daily ranges over a portion of the data set. The categories were selected so that each contains about one-third of the days

4. Ambient Temperature Range - The minimum and maximum temperature at Hockey observed for each day was listed. The Hockey site was chosen because it is the closest fixed station to the majority of the plume heights.

5. Total Precipitation - The total amount of precipitation in inches that fell during each day was provided.

6. Range of UV Radiation Peaks - The daily maximum UV radiation measurements in mW/cm^2 was presented for each day.

7. Wind Speed and Direction - The 1200 GMT, 850 mb facsimile maps were examined for wind speeds and directions for southwest Virginia. The speeds and directions were tabulated for each day.

8. Percent of Hours: Unstable, Neutral, Stable - The number of hours for each stability class was calculated for each day. The method utilized in determining stability is discussed in Section 10.0. The method is based on the use of the Bulk Richardson Number computed from Tower data.

9. Prevailing Circulation - Each day was assigned to one of seven categories as follows: strong cyclonic, weak cyclonic, cyclonic, strong anticyclonic, weak anticyclonic, anticyclonic, or mixed, based on examination of the 1200 GMT, 850 mb facsimile maps.

10. Prevailing Surface Wind Direction - The 45° sectors of wind directions which occurred most frequently among the hourly fixed-station observations were noted for each day.

11. Plume Height Distribution - The number of estimated hourly plume heights falling into four height ranges was tabulated each day for each stack. The plume height estimates were made using vertical profiles of temperature and wind speed. The method is discussed in Section 7.0.

Groups of days were then assigned into data periods designated as being predominantly synoptic or local based on the predominant airflow influence. For example, if the situation in Table 3 had occurred, the first 5 days would be classified as a synoptic period, and the last 3 days would be a local period.

TABLE 3. EXAMPLE CLASSIFICATION OF DATA PERIODS

Day	Classification	
March 20, 1977	SL	Snoptic
21	L	
22	S	
23	S	
24	S	
25	L	Local
26	LS	
27	SL	

Table 4 presents the 11 parameters for each of 31 data periods from November 22, 1976 through the end of the field study observed to have a relatively large amount of significant SO_2 and NO_x concentrations at the fixed monitoring stations. This table was derived from the complete compilation of data in which the same parameters were tablulated on a daily basis by considering only those periods in which significant SO_2 or NO_x concentrations occurred at more than one station for at least three-fourths of the days during the period or significant SO_2 or NO_x occurred at four or more stations on at least 2 days during the period. The table begins on November 22, 1976 since pollutant instrument calibration problems existed prior to this date.

The number of hours in each data period which each station recorded significant SO_2 concentrations are presented in Table 4. In the table each fixed station is represented by the first letter appearing in its name (i.e., C-Castlewood, T-Tower, etc.) followed by the number of significant concentration hours. The two plume height distribution columns of Table 4 apply to Stack 1 and Stack 2, respectively. The first number in both columns is the percentage of estimated hourly plume heights less than 250 m above plant base, the second number is the percentage between 250 m and 400 m, the third is the percent between 400 m and 600 m, and the fourth is the percent greater than 600 m. For the other parameters the values given in Table 4 are either maxima and minima of the parameter or the prevailing condition during the period.

RESULTS

By examining Table 4, several distinctions between synoptic and local periods become apparent. For instance, local periods generally had slightly lower plume heights; for Stack 1 the mean percent of plume heights lower than 250 m above plant base was 43.2 percent for synoptic periods compared to 50.5 percent for local periods. However, this difference is not statistically significant at the 95 percent confidence level. Local and synoptic periods also differed in the frequency distribution of the stability classes as evidenced

TABLE 4. DATA PERIOD SUMMARY

Date	Predominant Airflow Influence	Number of Hours Stations Measured Significant SO_2 Concentrations (see text)	Predominant Diurnal Variation in Vertical Temp. Diff.	Maximum and Minimum Temperature During Period (°C)	Total Precipitation (in) and Number of Days	Highest and Lowest Daily UV Radiation Peaks (mW/cm²)	1200 GMT 850 mb Predominant Wind Speed and Direction Ranges	Percent of Hours: U-Unstable, N-Neutral, S-Stable	Prevailing Circulation	Prevailing Surface Wind Direction Sectors	Percent Plume Height Distribution (see text) Stack 1	Stack 2
November 22, 1976 to December 1, 1976	Synoptic	T 23 L 0 C 2 J 0 H 2 K 1 M 0 N 27	Medium-Large	-14.3°C 13.9°C	0.52 4	Missing	20-30 Kts SW - WNW	U 5 N 33 S 62	Strong Cyclonic	225°-270°	51 36 11 2	58 33 9 0
December 2, 1976 to December 11, 1976	Local	T 6 L 0 C 3 J 0 H 1 K 23 M 2 N 1	Mixed	-10.0°C 8.6°C	1.07 5	Missing	10-30 Kts W	U 3 N 8 S 89	Mixed	225°-270°	56 39 4 1	78 18 4 0
December 12, 1976 to December 17, 1976	Synoptic	T 7 L 0 C 3 J 0 H 7 K 7 M 5 N 3	Small	-3.8°C 8.9°C	0.42 2	Missing	20-30 Kts SSW-WNW	U 0 N 19 S 81	Cyclonic	225°-270°	35 45 20 0	58 33 9 0
December 18, 1976 to December 20, 1976	Local	T 4 L 0 C 4 J 0 H 8 K 13 M 1 N 1	Large	-3.5°C 12.3°C	0.28 1	Missing	20-30 Kts SW-NW	U 0 N 21 S 79	Mixed	180°-225°	53 39 8 0	82 17 1 0
December 21, 1976 to December 23, 1976	Synoptic	T 12 L 1 C 2 J 0 H 5 K 2 M 2 N 0	Medium	-13.5°C -0.4°C	0	Missing	25-35 Kts WSW-NW	U 0 N 51 S 49	Strong Cyclonic	225°-270°	44 50 4 1	72 25 1 1
December 24, 1976 to December 25, 1976	Local	T 4 L 0 C 0 J 0 H 0 K 14 M 0 N 3	Medium-Large	-11.2°C 2.7 C	0.03 1	0.5	25-35 Kts SW-NW	U 0 N 8 S 92	Mixed	180°-270°	65 33 2 0	81 19 0 0
December 26, 1976 to January 2, 1977	Synoptic	T 22 L 1 C 4 J 0 H 0 K 2 M 2 N 5	Small	-17.3°C 5.8°C	0.42 1	0.5	30-40 Kts W-NW	U 0 N 41 S 59	Strong Cyclonic	225°-270°	39 48 11 2	58 34 6 1

(continued)

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TABLE 4. (continued)

Date	Predominant Airflow Influence	Number of Hours Stations Measured Significant SO_2 Concentrations (see text)	Predominant Diurnal Variation in Vertical Temp. Diff.	Maximum and Minimum Temperature During Period (°C)	Total Precipitation (In) and Number of Days	Highest and Lowest Daily UV Radiation Peaks (mW/cm^2)	1200 GMT 850 mb Predominant Wind Speed and Direction Ranges	Percent of Hours: U-Unstable, N-Neutral, S-Stable	Prevailing Circulation	Prevailing Surface Wind Direction Sectors	Percent Plume Height Distribution (see text)	
											Stack 1	Stack 2
January 6, 1977 to January 7, 1977	Synoptic	T 0 L 0 C 6 J 28 H 5 K 0 M 0 N 4	Small- Medium	-9.7°C 0.3°C	0.15 2	0.5	10-35 Kts W-WNW	U 0 N 25 S 75	Mixed	225°-315°	19 71 6 4	54 46 0 0
January 8, 1977 to January 9, 1977	Local	T 0 L 0 C 8 J 20 H 9 K 0 M 0 N 0	Small	-10.8°C 6.0°C	0.34 1	0.5	15 Kts SW-W	U 0 N 4 S 96	Mixed	225°-270° 45°- 90°	42 50 8 0	69 31 0 0
January 10, 1977 to January 12, 1977	Synoptic	T 4 L 0 C 4 J 39 H 2 K 7 M 0 N 0	Small	-18.7°C 5.4°C	0	0.5	35-40 Kts WSW-NW	U 0 N 46 S 54	Strong- Cyclonic	270°-315°	51 35 8 6	56 30 10 4
January 13, 1977 to January 14, 1977	Local	T 1 L 0 C 2 J 0 H 0 K 0 M 0 N 0	Small	-11.7°C 5.7°C	0.18 1	0.5	15-35 Kts SW-WNW	U 0 N 0 S 100	Mixed	45°-90° 225°-270°	17 51 2 0	87 11 2 0
January 15, 1977 to February 5, 1977	Synoptic	T 36 L 4 C 11 J 6 H 19 K 4 M 6 N 29	Small	-25.7°C 4.5°C	0.21 2	0.5-1.0	15-35 Kts SW-WNW	U 1 N 38 S 61	Strong- Cyclonic	225°-315°	30 50 19 2	53 38 8 2
February 9, 1977 to February 10, 1977	Synoptic	T 10 L 0 C 6 J 1 H 9 K 8 M 2 N 5	Medium- Large	-4.0°C 9.5°C	0	0.5	15-20 Kts W	U 0 N 21 S 79	Weak- Cyclonic	225°-270°	44 56 0 0	100 0 0 0
February 11, 1977 to February 12, 1977	Local	T 4 L 3 C 7 J 0 H 3 K 0 M 2 N 2	Mixed	3.7°C 10.6°C	0.08 1	0.5	15-20 Kts SW-W	U 0 N 8 S 92	Anti- Cyclonic	180° 270°	71 27 2 0	100 0 0 0

(continued)

TABLE 4. (continued)

Date	Predominant Airflow Influence	Number of Hours Stations Measured Significant SO_2 Concentrations (see text)	Predominant Diurnal Variation in Vertical Temp. Diff.	Maximum and Minimum Temperature During Period (°C)	Total Precipitation (in) and Number of Days	Highest and Lowest Daily UV Radiation Peaks (mW/cm^2)	1200 GMT 850 mb Predominant Wind Speed and Direction Ranges	Percent of Hours: U-Unstable, N-Neutral, S-Stable	Prevailing Circulation	Prevailing Surface Wind Direction Sectors	Percent Plume Height Distribution (see text) Stack 1	Stack 2
February 18, 1977 to February 19, 1977	Local	T 4 L 0 C 0 J 0 H 1 K 2 M 2 N 0	Small-Medium	-13.1°C 4.0°C	0.18 1	0.5	20-25 Kts W	U 0 N 21 S 79	Mixed	180°-270°	48 42 10 0	73 23 4 0
February 20, 1977 to February 25, 1977	Synoptic	T 5 L 0 C 0 J 1 H 1 K 3 M 0 N 0	Mixed	-7.8°C 15.4°C	0.33 1	0.5-1.0	25-40 Kts SW-NW	U 1 N 40 S 58	Strong-Cyclonic	225°-270°	38 33 29 0	47 37 16 0
February 28, 1977 to March 7, 1977	Synoptic	T 5 L 0 C 0 J 0 H 0 K 0 M 0 N 1	Large	-5.8°C 15.6°C	0.25 4	0.5-1.0	Missing	U 3 N 26 S 71	Mixed	225°-270°	56 23 6 15	65 19 2 15
March 8, 1977 to March 10, 1977	Local	T 3 L 0 C 1 J 0 H 0 K 0 M 0 N 0	Large	0.3°C 16.4°C	0	1.0	Missing	U 18 N 8 S 74	Mixed	180°-225°	36 42 19 3	82 12 6 0
March 15, 1977 to March 25, 1977	Local	T 4 L 0 C 1 J 0 H 0 K 0 M 0 N 1	Large	11.5°C 20.5°C	0	1.0	20 Kts WNW	U 13 N 17 S 70	Mixed	180°-225°	96 4 0 0	100 0 0 0
March 20, 1977 to March 24, 1977	Synoptic	T 4 L 0 C 4 J 0 H 4 K 0 M 2 N 1	Mixed	4.1°C 13.3°C	0.40 2	0.5-1.5	Missing	U 3 N 36 S 61	Strong-Cyclonic	270°-315°	23 49 28 0	55 37 8 0
April 3, 1977 to April 20, 1977	Local	T 3 L 1 C 0 J 10 H 2 K 0 M 1 N 1	Large	-2.1°C 25.5°C	5.46 5	0.5-1.9	Missing	U 12 N 12 S 65	Weak Anti-Cyclonic	45°-90° 225°-270°	59 30 11 0	34 38 22 6

(continued)

TABLE 4. (continued)

Date	Predominant Airflow Influence	Number of Hours Stations Measured Significant SO_2 Concentrations (see text)	Predominant Diurnal Variation in Vertical Temp. Diff.	Maximum and Minimum Temperature During Period (°C)	Total Precipitation (in) and Number of Days	Highest and Lowest Daily UV Radiation Peaks, (mW/cm²)	1200 GMT 850 mb Predominant Wind Speed and Direction Ranges	Percent of Hours: U-Unstable, N-Neutral, S-Stable	Prevailing Circulation	Prevailing Surface Wind Direction Sectors	Percent Plume Height Distribution (see text)	
											Stack 1	Stack 2
May 1, 1977 to May 2, 1977	Synoptic	T 8 L 0 C 0 J 0 H 0 K 0 M 0 N 1	Mixed	12.6°C 21.5°C	0.79 1	0.5-1.0	5-15 Kts SW-NW	U 29 N 9 S 62	Weak Anti-cyclonic	225°-270°	52 42 6 0	75 25 0 0
May 3, 1977 to May 4, 1977	Local	T 6 L 0 C 0 J 0 H 0 K 0 M 0 N 1	Missing	14.1°C 20.7°C	Missing	Missing	5-15 Kts SW-W	U 11 N 61 S 28	Weak Anti-cyclonic	45°-90° 180°-225°	29 48 19 4	65 23 12 0
May 31, 1977 to June 1, 1977	Synoptic	T 8 L 1 C 0 J 0 H 2 K 0 M 0 N 6	Medium-large	15.4°C 24.8°C	0.34 1	1.7-2.3	5-25 Kts W-WSW	U 23 N 13 S 64	Cyclonic	225°-270°	85 10 4 0	90 6 4 0
June 2, 1977 to June 5, 1977	Local	T 4 L 0 C 0 J 3 H 2 K 1 M 1 N 3	Large	12.7°C 26.9°C	0	1.8-2.9	15 Kts WSW-W	U 33 N 7 S 60	Mixed	225°-360° 45°-90°	64 36 0 0	62 37 0 0
June 24, 1977 to July 3, 1977	Synoptic	T 13 L 0 C 0 J 0 H 2 K 0 M 1 N 0	Medium	15.8°C 26.5°C	2.52 7	0.5-2.5	10-30 Kts WSW-W	U 9 N 28 S 63	Mixed	225°-270°	48 41 10 1	56 36 8 0
July 4, 1977 to July 8, 1977	Local	T 13 L 0 C 0 J 0 H 6 K 2 M 5 N 3	Medium	18.9°C 30.7°C	0	0.7-2.0	10-15 Kts WNW-NW	U 34 N 4 S 61	Weak Anti-cyclonic	270°-315°	24 50 17 3	43 51 6 0
July 9, 1977 to July 16, 1971	Synoptic	T 0 L 0 C 0 J 1 H 0 K 0 M 1 N 1	Missing	19.1°C 30.8°C	Missing	Missing	10-15 Kts WSW-N	U 38 N 2 S 51	Weak Anti-cyclonic	315°-360°	33 40 18 10	58 25 11 6

(continued)

TABLE 4. (continued)

Date	Predominant Airflow Influence	Number of Hours Stations Measured Significant SO_2 Concentrations (see text)	Predominant Diurnal Variation in Vertical Temp. Diff.	Maximum and Minimum Temperature During Period (°C)	Total Precipitation (In) and Number of Days	Highest and Lowest Daily UV Radiation Peaks (mW/cm²)	1200 GMT 850 mb Predominant Wind Speed and Direction Ranges	Percent of Hours: U-Unstable, N-Neutral, S-Stable	Prevailing Circulation	Prevailing Surface Wind Direction Sectors	Percent Plume Height Distribution (see text) Stack 1	Stack 2
July 17, 1977	Local	T 13 I 0	Missing	19.8°C	Missing	0.9-1.7	10-15 Kts	Missing	Weak	315°-360°	28	58
to		C 0 J 1					W		Anti-		37	23
July 21, 1977		H 5 K 0		31.8°C					cyclonic		26	18
		M 2 N 1									8	2
August 12, 1977	Local	T 7 L 0	Missing	18.4°C	Missing	0.7-1.3	Missing	Missing	Weak	180°-225°	18	52
to		C 0 J 0							Anti-		38	30
August 15, 1977		H 4 K 1		27.2°C					cyclonic		12	11
		M 1 N 0									2	1
September 15, 1977	Local	T 4 L 0	Missing	10.5°C	0.75	0.8-0.9	5-25 Kts	Missing	Mixed	180°-225°	12	52
to		C 1 J 1			5		SSW-NW				48	30
September 24, 1977		H 8 K 0		24.5°C							9	11
		M 0 N 0									1	[illegible]

by Table 5. The more frequent incidence of stable conditions for local periods may have been a contributing factor to the lower plume heights calculated during these periods. Table 5 also shows there was a substantial difference in the frequency of neutral conditions between local and synoptic periods. This difference is significant at the 95 percent confidence level. The greater frequency of occurrence of neutral stability during synoptic periods may be attributed to greater wind speeds and the resulting enhancement of vertical mixing.

TABLE 5. PERCENTAGE OF STABILITY CLASSES FOR LOCAL AND SYNOPTIC PERIODS (BASED ON THE 31 PERIODS WITH SIGNIFICANT CONCENTRATIONS IN TABLE 4).

	Unstable	Neutral	Stable
Local	9.5%	13.8%	75.8%
Synoptic	7.5%	26.1%	63.3%

Table 6 shows the frequency distribution of prevailing surface wind direction sectors for synoptic and local periods. Synoptic periods are predominantly associated with a wind direction in the 225°-270° sector. The most frequently observed wind direction during local periods is more varied with both the 180°-225° and the 225°-270° sectors being common. There is a secondary peak in the 45°-90° sector.

TABLE 6. NUMBER OF LOCAL AND SYNOPTIC PERIODS FOR PREDOMINANT SURFACE WIND DIRECTIONS (BASED ON PERIODS IN TABLE 4)

	Number of Cases	
Wind Direction Sector	Local	Synoptic
0° - 45°	0	0
45° - 90°	5	0
90° - 135°	0	0
135° - 180°	0	0
180° - 225°	8	0
225° - 270°	8	12
270° - 315°	2	4
315° - 360°	2	1

A striking difference between synoptic and local periods is illustrated in Table 4 for periods between December 18, 1976 and January 2, 1977. The two local periods during that time had lower plume heights and markedly less incidence of neutral stability compared to the two synoptic periods.

A noteworthy period among the periods with the highest frequency of significant concentrations was the 2-day synoptic period of February 9-10, 1977. During this period, all the fixed stations with the exception of Lambert, had at least 1 hour of a significant SO_2 concentration. An examination of the calculated plume height distribution for this period reveals that all the plume heights for Stack 1 were less than 400 m and all the plume heights for Stack 2 were less than 250 m above plant base. A contributing factor to the lower plume heights and hence the large concentrations may have been the large incidence of stable conditions (79 percent of the hours were stable) for this period. The predominant surface wind direction for this period was 225°-270°. Six of the eight fixed stations are downwind when winds are within this sector or within 20° of this sector.

CONCLUSIONS

It was possible to divide the monitoring data into data periods in which the airflow was locally or synoptically dominated based on the observed characteristics of the winds within the monitoring network. This delineation of the data allowed the identification of periods of significant plume impact on the fixed-station network. Differences in frequencies of wind direction sectors, stability classes and plume heights were noted between the synoptic-flow and local-flow periods.

SECTION 5

STATISTICAL ANALYSIS OF PLANT EMISSIONS AND MEASURED AMBIENT POLLUTANT CONCENTRATIONS

General trends and patterns in pollutant data usually are apparent in joint frequency distributions of concentration and other physical parameters. Such analyses have been performed with the hourly concentration data from each of the eight fixed stations and with the plant emission data. In addition, the dates and times of the highest SO_2 and NO_x concentrations have been produced for each station. Mean pollutant concentrations for the entire monitoring period were also computed. A review of these statistics has guided subsequent analysis of the data.

PLANT EMISSIONS DATA

For each generating unit the following joint frequency distributions were produced:

- Generator load versus hour
- Exhaust gas temperature versus hour
- Exhaust flow rate versus hour
- Estimated SO_2 emission rate versus hour
- Estimated NO emission rate versus hour.

In addition, for Unit #3, frequency distributions of measured SO_2 emission rate versus hour and measured NO emission rate versus hour were generated.

To typify the Clinch River plant operating conditions, the most frequent categories of generator load, exhaust gas temperature, exhaust flow rate, estimated SO_2 emission rate, and estimated NO emission rate were identified. These ranges appear in Table 7. The most frequently measured SO_2 emission rates for Unit #3 (Stack 2) were found to be between 250 and 300 g/sec;* the most frequently measured NO emission rate was between 200 and 225 g/sec. The estimated pollutant emission rates for all three units were computed in Phase II of the study using linear regression formulas derived from the available measured emission rates for Unit #3 and the generator load and sulfur content data provided by the power company. The estimates are useful for periods when the stack monitors were not available or not working. For other periods useful emission estimates can be computed by using the ratio of measured emission to load for Unit #3 to scale the emissions for the other units to the measured loads.

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* The measured SO_2 and NO stack concentration distributions were compiled in 50 g/sec increments and 25 g/sec increments, respectively.

TABLE 7. MOST FREQUENT RANGES OF PLANT PARAMETERS

Unit #	Exhaust Temperature (°K)	Exhaust Airflow (m3/sec)	Generator Load (MW)	Estimated SO_2 Emission (g/sec)	Estimated NO Emission (g/sec)
1	380-390	320-340	200-225	300-325	200-225
2	390-400	360-380	225-250	275-300	200-225
3	380-390	320-340	225-250	275-300	200-225

Table 8 shows the typical diurnal variation of generator loads for each unit. The pattern indicates a rather abrupt increase in load for Unit #1 between 7 a.m. and 8 a.m. and for Unit #2 between 6 a.m. and 7 a.m. A more gradual early morning increase is noted for Unit #3. Most frequently, the generator load is 200-225 MW from 8 a.m. through 11 p.m. for Unit #1 and 225-250 MW for Units #2 and #3. Another abrupt change in load frequently occurs between midnight and 1 a.m. for Units #1 and #3, when the loads typically drop from 200-225 MW to 125-150 MW. The same drop in load occurs from 11 p.m. to 1 a.m. for Unit #2.

Table 7 shows that the most frequent SO_2 emission rates are 300-325 g/sec for Unit #1 and 275-300 g/sec for each of Units #2 and #3. Emission rates for SO_2 as high as 525-550 g/sec were estimated for Units #1 and #3, while three cases of SO_2 emissions in the 550-575 g/sec range were estimated for Unit #2. The majority of the very high SO_2 emission rates occurred in the afternoon when typically dispersion conditions are best. The highest estimated NO emission rates were 300-325 g/sec for Unit #3 and 275-300 g/sec for Units #1 and #2. Similar to SO_2, generally the highest NO emission rates occurred in the afternoon.

Exhaust air flow rates and exhaust temperatures were generally well correlated with the trends in generator load conditions, as peak flow rates and exhaust temperatures generally occurred in the afternoon. A few cases of flow rates as high as 420 m^3/sec and temperatures as high as 450° K were noted.

TABLE 8. MOST FREQUENT RANGES OF GENERATOR LOAD BY TIME OF DAY

Hour	Unit 1 Load (MW)	Unit 2 Load (MW)	Unit 3 Load (MW)
1	125-150	125-150	125-150
2	125-150	150-175	125-150
3	125-150	150-175	125-150
4	125-150	125-150	125-150
5	125-150	150-175	125-150
6	125-150	150-175	125-150
7	125-150	225-250	150-175
8	200-225	225-250	200-225
9	225-250	225-250	225-250
10	225-250	225-250	225-250
11	225-250	225-250	225-250
12	200-225	225-250	225-250
13	200-225	225-250	225-250
14	200-225	225-250	225-250
15	200-225	225-250	225-250
16	200-225	225-250	225-250
17	225-250	225-250	225-250
18	200-225	225-250	225-250
19	200-225	225-250	200-225
20	200-225	225-250	225-250
21	200-225	225-250	200-225
22	200-225	225-250	200-225
23	200-225	200-225	200-225
24	200-225	150-175	200-225

AMBIENT POLLUTION CONCENTRATIONS AT FIXED STATIONS

Ambient SO_2 concentrations at the monitoring stations never exceeded the secondary National Ambient Air Quality Standard of 500 ppb averaged over 3 hours, the primary standard of 140 ppb averaged over 24 hours, or the annual standard of 30 ppb. The low sulfur coal (generally less than 1 percent sulfur) burned by the plant was probably a major reason why higher values were not observed.

Mean pollutant concentration measurements were computed over the period for which there is properly calibrated data (i.e., after Julian Day 286 of 1976 for SO_2 and after Julian Day 324 of 1976 for NO_x, NO_2, and NO). The means appear in Table 9. The closest station (Tower) recorded the highest mean SO_2 and NO_x concentrations while the most distant stations (Kents and Nashs) recorded the lowest mean SO_2. However, both Munsey and Hockey showed lower NO_x means than Kents and Nashs, while Castle, located 8.3 km from the plan showed an NO_x mean almost as high as that for Tower (only 3.4 km distant). When working with mean concentrations as small as those in Table 9, recorded at the fixed stations, differences between stations may not be meaningful due to the fact that the vast majority of the hourly measurements are at or below the sensing threshold of the instrument. The sensing threshold for the SO_2 analyzer and the NO_x analyzer were approximately 5 to 8 ppb and 10 ppb respectively. Slight errors in calibration can have a substantial effect on the result when the mean of a large quantity of these very small concentrations is computed. In addition the means for each station are obviously highly dependent upon the distribution of winds and other meteorological factors during the different periods that the stations operated.

TABLE 9. MEAN POLLUTANT CONCENTRATIONS OVER THE MONITORING PERIOD (ppb)

Station	SO_2	NO_x	NO_2	NO
Tower	12	29	15	15
Munsey	4	7	5	1
Hockey	6	5	3	2
Lambert	3	-	-	-
Johnson	8	-	-	-
Castle	6	25	11	13
Kents	1	11	7	3
Nashs	2	15	9	6

Much greater confidence can be placed in individual high pollutant readings. Tables 10 and 11 contain a tabulation of the 10 highest hourly average SO_2 and NO_x concentrations at each of the eight fixed stations. A particularly interesting feature of the high SO_2 concentrations is the fact that at four stations (Tower, Nashs, Castle and Lambert) most of the high values occurred in the late morning. For example, all of the 10 highest SO_2 concentrations at Castle occurred between 9 a.m. and noon. Munsey, along with the ridge-top stations (Hockey, Johnson, and Kents) do not show this phenomenon. It is hypothesized that fumigation of the plume, as early morning inversions were being eroded from the surface, is the cause of these results. Investigation of this hypothesis is fully described in Section 8. This pattern is less evident with NO_x, although Nashs and Castle each showed 7 cases of the 10 highest NO_x concentrations between 10 a.m. and noon. All 10 of the highest concentrations at Hockey occurred between 3 a.m. and 11 a.m., and all 10 highest NO_x values at Munsey occurred between 6 a.m. and 11 a.m.

Tables 12 through 19 present the frequency distributions of measured hourly average SO_2 concentrations at the eight fixed stations stratified by hour of the day. Figures 3 through 10 show the mean SO_2 concentrations for each hour of the day for each of the eight stations. Tower, Castlewood, Munsey, and Nashs have distinct peaks in the late morning; the maximum average concentration is reached at 1100 EST at these stations. Less pronounced maxima are also noted for Lambert and Kents for 1100 EST. These results also support the hypothesis of prolonged fumigation incidents in the late morning hours as a major cause for elevated SO_2 levels in the vicinity of the Clinch River Plant. With the exception of Kents, which is the most distant station, all six stations mentioned above are non-ridgetop stations. The ridgetop stations, Hockey and Johnson, show substantially different diurnal patterns than the other six stations. Johnson's average concentration is the highest during the hours 0100-0900 EST; a distinct minimum is reached by late afternoon. At Hockey two distinct peaks are evident, one occurring at 0300-0400 EST and the second occurring from 0900-1000 EST. The high nighttime concentrations at these two ridgetop stations are probably caused by stable plumes from the power plant passing near ridgetop level. The 0900-1000 maximum at Hockey may be related to the fumigation phenomenon at the six lower-level stations.

Listed below are the percent frequencies of occurrence of SO_2 concentrations less than 10 ppb:

Tower	75.5%
Munsey	89.2%
Castle	84.2%
Nashs	93.9%
Hockey	85.0%
Lambert	92.0%
Johnson	74.1%
Kents	95.7%

TABLE 10. TEN HIGHEST HOURLY AVERAGE SO_2 CONCENTRATIONS OBSERVED AT EACH MONITORING SITE

	Tower			Hockey			Kent			Nash		
Rank	SO_2 Conc. (ppb)	Date	Hour	SO_2 Conc. (ppb)	Date	Hour	SO_2 Conc. (ppb)	Date	Hour	SO_2 Conc. (ppb)	Date	Hour
1	344	7/25/77	12	318	6/30/77	5	200	2/22/77	13	105	1/23/77	14
2	317	7/25/77	13	219	12/14/76	9	180	10/23/76	3	77	6/7/77	12
3	308	11/25/76	10	215	7/4/77	5	134	2/22/77	12	76	5/17/77	10
4	274	7/18/77	10	190	10/23/76	3	127	12/10/76	9	75	11/2/76	11
5	268	7/25/77	11	180	12/21/76	24	85	12/10/76	6	71	2/10/77	13
6	261	12/25/76	2	152	10/12/76	9	80	12/19/76	6	70	2/10/77	12
7	260	8/14/77	11	150	12/22/76	2	75	12/19/76	7	67	1/28/77	11
8	259	7/6/77	8	148	7/5/77	5	71	12/10/76	7	66	6/5/77	11
9	252	8/7/77	10	146	2/2/77	3	66	12/19/76	5	66	11/26/77	11
10	251	8/1/77	12	138	11/4/76	9	61	12/25/76	6	63	6/1/77	8

	Castle			Mumsey			Johnson			Lambert		
Rank	SO_2 Conc. (ppb)	Date	Hour	SO_2 Conc. (ppb)	Date	Hour	SO_2 Conc. (ppb)	Date	Hour	SO_2 Conc. (ppb)	Date	Hour
1	268	11/2/76	9	182	7/5/77	8	246	3/1/77	24	77	5/16/77	11
2	260	2/8/77	11	178	7/5/77	9	199	5/10/77	23	71	4/19/77	11
3	241	10/29/76	11	167	2/2/77	3	197	5/11/77	3	70	2/11/77	12
4	218	2/8/77	10	135	8/15/77	15	161	8/2/77	1	68	1/28/77	12
5	197	3/21/77	11	125	2/18/77	16	136	5/15/77	11	67	2/16/77	10
6	172	2/8/77	12	119	12/22/76	2	131	3/1/77	23	57	1/28/77	12
7	149	10/29/76	9	119	2/18/77	15	127	1/11/77	6	48	2/11/77	11
8	141	2/11/77	10	111	5/16/77	10	124	1/11/77	5	44	2/11/77	13
9	137	3/21/77	12	99	2/16/77	11	110	8/2/77	3	42	12/23/76	17
10	135	2/11/77	12	99	2/16/77	13	109	1/11/77	7	33	12/18/76	19

TABLE 11. TEN HIGHEST HOURLY AVERAGE NO_x CONCENTRATIONS OBSERVED AT EACH MONITORING SITE

	Tower			Hockey			Kents		
Rank	NO_x Conc. (ppb)	Date	Hour	NO_x Conc. (ppb)	Date	Hour	NO_x Conc. (ppb)	Date	Hour
1	619	1/28/77	10	568	6/30/77	5	353	8/13/77	22
2	549	12/30/76	14	399	7/5/77	3	103	2/19/77	4
3	482	3/15/77	11	329	8/15/77	9	101	8/8/77	7
4	467	12/30/76	20	255	6/30/77	4	92	12/14/76	11
5	457	7/7/77	8	219	7/6/77	3	89	11/24/76	24
6	448	1/26/77	20	205	7/2/77	6	83	12/14/76	12
7	430	1/28/77	13	170	4/20/77	4	80	8/377	5
8	420	12/23/76	10	164	3/21/77	11	79	8/6/77	12
9	414	12/30/76	16	146	5/14/77	10	79	12/19/76	6
10	397	12/23/76	9	130	7/20/77	3	78	1/13/77	17

	Nasns			Castle			Munsey		
Rank.	NO_x Conc. (ppb)	Date	Hour	NO_x Conc. (ppb)	Date	Hour	NO_x Conc. (ppb)	Date	Hour
1	834	8/10/77	16	816	2/15/77	15	419	3/9/77	9
2	601	6/7/77	12	589	2/8/77	11	408	3/9/77	8
3	553	8/10/77	15	464	2/8/77	10	297	7/6/77	9
4	262	2/10/77	12	435	2/11/77	9	280	7/6/77	8
5	235	7/8/77	10	410	2/11/77	10	276	3/9/77	7
6	229	2/10/77	11	394	2/11/77	11	252	3/9/77	10
7	228	7/12/77	10	375	2/8/77	12	206	6/16/77	8
8	226	2/11/77	12	365	2/11/77	12	186	3/21/77	11
9	211	6/7/77	13	350	2/10/77	10	173	3/9/77	11
10	207	5/6/77	10	290	2/1177	8	170	7/2/77	6

TABLE 12. FREQUENCY DISTRIBUTION OF SO_2 VS. HOUR FROM 76286 to 77273, TOWER SITE

(ROW & COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS)

	SO_2 ($\mu g/m^3$)															
HOUR	5.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0	80.0	100.0	150.0	200.0	300.0	500.0	TOTALS
1.0	241	27	6	8	4	7	7	6	2	1	3	1	0	0	0	313
2.0	230	26	9	9	5	7	4	3	0	1	1	2	1	1	0	299
3.0	241	28	7	9	7	6	6	1	0	2	1	3	0	0	0	311
4.0	237	30	9	9	4	8	4	6	2	0	0	3	0	0	0	312
5.0	235	26	13	11	5	5	4	2	0	3	1	2	1	1	0	309
6.0	223	34	4	14	9	3	8	2	3	4	0	4	0	0	0	308
7.0	219	27	12	12	12	3	7	5	4	3	1	2	0	0	0	307
8.0	205	26	11	15	6	12	6	5	2	9	5	2	2	2	0	308
9.0	181	31	15	10	9	3	11	8	6	4	7	13	7	0	0	305
10.0	152	28	16	19	6	11	13	16	11	8	8	10	5	4	1	308
11.0	136	29	16	16	12	10	11	9	12	17	14	9	8	6	0	305
12.0	140	32	16	16	6	8	20	13	14	18	15	7	3	1	1	310
13.0	147	35	13	13	9	18	21	9	13	10	10	8	2	1	1	310
14.0	150	30	23	12	15	6	16	13	10	16	5	7	2	1	0	306
15.0	157	34	16	19	12	4	16	14	14	10	10	5	1	0	0	312
16.0	175	37	14	15	7	16	12	11	3	18	4	5	0	0	0	317
17.0	198	32	11	12	11	10	15	8	7	8	1	3	0	0	0	316
18.0	214	35	12	13	10	7	5	5	6	4	1	4	0	0	0	316
19.0	230	36	9	16	5	4	4	3	3	3	1	1	1	0	0	316
20.0	229	37	17	13	3	2	5	4	0	3	0	2	1	0	0	316
21.0	235	28	14	12	7	6	7	1	1	1	2	0	0	0	0	314
22.0	234	36	7	15	6	2	5	4	1	1	2	1	0	0	0	314
23.0	241	29	11	9	4	7	5	3	2	1	1	1	0	0	0	314
24.0	240	28	14	8	1	8	5	4	1	2	0	1	1	0	0	313
TOTALS	4890	741	295	305	175	173	217	155	117	147	93	96	35	17	3	

29 SO2 VALUES LESS THAN 0.000 .0 SO2 VALUES LARGER THAN 500.0

TABLE 13. FREQUENCY DISTRIBUTION OF SO_2 VS. HOUR FROM 76286 TO 77273, MUNSEY SITE

(ROW & COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS)

SO_2 ($\mu g/m^3$)

HOUR	5.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0	80.0	100.0	150.0	200.0	300.0	500.0	TOTALS
1.0	286	32	7	5	3	3	4	1	0	0	0	0	0	0	0	341
2.0	288	29	9	6	5	3	2	0	0	0	0	1	0	0	0	343
3.0	286	23	12	9	3	2	3	1	1	0	0	0	1	0	0	341
4.0	285	28	13	5	2	5	3	0	0	0	0	0	0	0	0	341
5.0	284	26	11	9	4	2	2	1	0	0	0	0	0	0	0	339
6.0	285	25	11	5	9	1	2	1	1	0	0	0	0	0	0	340
7.0	287	20	18	6	4	2	2	0	0	1	0	0	0	0	0	340
8.0	279	22	13	8	7	4	2	1	0	1	0	0	1	0	0	338
9.0	256	29	10	11	9	5	4	4	1	2	0	0	1	0	0	332
10.0	243	29	15	13	6	7	10	4	2	4	1	1	0	0	0	335
11.0	231	33	18	13	10	6	9	5	2	6	1	0	0	0	0	334
12.0	239	41	12	15	8	8	5	3	3	2	0	0	0	0	0	336
13.0	247	50	17	8	9	3	4	3	0	0	1	0	0	0	0	342
14.0	244	50	15	10	5	5	2	2	2	0	0	0	0	0	0	335
15.0	253	49	19	4	7	1	3	0	0	0	0	2	0	0	0	338
16.0	254	50	18	7	6	5	1	0	0	0	0	1	0	0	0	342
17.0	266	43	20	9	3	1	1	0	0	0	0	0	0	0	0	343
18.0	278	30	21	7	3	2	2	0	0	0	0	0	0	0	0	343
19.0	286	32	13	6	2	2	2	0	0	0	0	0	0	0	0	343
20.0	283	33	14	7	2	1	4	0	0	0	0	0	0	0	0	344
21.0	289	25	12	6	5	3	2	1	0	0	0	0	0	0	0	343
22.0	286	24	11	8	9	2	1	0	1	0	0	0	0	0	0	342
23.0	279	30	13	8	7	3	1	0	0	0	1	0	0	0	0	342
24.0	287	22	14	6	5	4	2	0	0	0	1	1	0	0	0	342
TOTALS	6501	775	336	191	133	80	73	27	13	16	5	6	3	0	0	

0 SO2 VALUES LESS THAN 0.000   0 SO2 VALUES LARGER THAN 500.0

TABLE 14. FREQUENCY DISTRIBUTION OF SO_2 VS. HOUR FROM 76286 TO 77273, CASTLE SITE (ROW & COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS)

SO_2 ($\mu g/m^3$)

HOUR	5.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0	80.0	100.0	150.0	200.0	300.0	500.0	TOTALS
1.0	145	15	3	3	4	1	2	0	0	0	0	0	0	0	0	173
2.0	143	17	3	2	4	1	1	1	0	0	0	0	0	0	0	172
3.0	138	22	7	2	2	0	1	0	0	0	0	0	0	0	0	172
4.0	146	12	7	5	1	0	1	0	0	0	0	0	0	0	0	172
5.0	139	16	12	1	2	1	0	0	0	0	0	0	0	0	0	171
6.0	140	12	11	4	3	1	0	0	0	0	0	0	0	0	0	171
7.0	133	21	10	3	2	1	0	1	0	0	0	0	0	0	0	171
8.0	122	24	13	4	3	1	0	1	0	2	0	0	0	0	0	170
9.0	102	29	19	3	6	1	1	0	1	1	0	3	0	1	0	167
10.0	91	28	17	9	7	6	2	1	0	1	0	3	0	1	0	166
11.0	84	17	14	12	15	1	7	6	5	1	0	2	1	2	0	167
12.0	88	15	15	10	9	10	9	5	0	0	2	2	1	0	0	166
13.0	94	14	12	10	15	6	5	3	5	1	2	0	0	0	0	167
14.0	104	11	15	12	7	7	2	2	2	2	0	0	0	0	0	164
15.0	110	16	11	8	5	7	5	2	0	0	0	0	0	0	0	164
16.0	115	19	12	5	7	5	3	1	0	0	0	0	0	0	0	167
17.0	125	15	10	8	6	1	4	0	0	0	0	0	0	0	0	169
18.0	132	16	9	4	4	1	1	0	0	0	1	0	0	0	0	168
19.0	135	21	4	4	3	0	1	0	0	0	0	1	0	0	0	169
20.0	140	16	6	4	2	0	0	0	0	0	0	0	0	0	0	168
21.0	140	18	6	2	2	0	0	0	1	0	0	0	0	0	0	169
22.0	138	20	4	3	2	1	0	1	0	0	0	0	0	0	0	169
23.0	137	18	6	3	4	0	1	0	0	0	0	0	0	0	0	169
24.0	145	14	6	1	3	3	0	1	0	0	0	0	0	0	0	173
TOTALS	2986	426	232	122	118	55	46	25	14	8	5	11	2	4	0	

0 SO2 VALUES LESS THAN 0.000 0 SO2 VALUES LARGER THAN 500.0

TABLE 15. FREQUENCY DISTRIBUTION OF SO$_2$ VS. HOUR FROM 76286 TO 77273, NASHS SITE

(ROW & COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS)

SO$_2$ (µg/m^3)

HOUR	5.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0	80.0	100.0	150.0	200.0	300.0	500.0	TOTALS
1.0	264	32	2	2	2	0	1	1	0	0	0	0	0	0	0	304
2.0	263	33	3	3	1	1	0	0	1	0	0	0	0	0	0	305
3.0	262	32	4	2	2	0	0	0	1	0	0	0	0	0	0	303
4.0	263	34	3	1	0	1	1	0	1	0	0	0	0	0	0	304
5.0	260	33	2	4	0	0	0	1	1	0	0	0	0	0	0	301
6.0	258	34	5	1	2	0	1	0	1	0	0	0	0	0	0	302
7.0	261	34	3	0	1	1	1	1	1	0	0	0	0	0	0	303
8.0	258	34	6	1	1	0	0	0	1	1	0	0	0	0	0	302
9.0	249	36	3	3	1	1	3	3	0	0	0	0	0	0	0	299
10.0	223	43	12	7	6	3	5	2	1	2	0	0	0	0	0	304
11.0	193	47	12	12	10	8	6	7	2	5	1	0	0	0	0	303
12.0	198	45	12	11	7	5	8	8	3	2	1	0	0	0	0	300
13.0	209	47	8	11	7	7	6	3	2	1	1	0	0	0	0	302
14.0	221	49	10	5	5	2	6	0	1	0	0	1	0	0	0	300
15.0	234	48	7	7	0	2	4	1	2	0	0	0	0	0	0	305
16.0	237	44	10	5	5	0	4	1	0	0	0	0	0	0	0	306
17.0	250	40	7	6	2	0	1	0	0	0	0	0	0	0	0	306
18.0	252	40	4	6	0	2	2	0	0	0	0	0	0	0	0	306
19.0	258	38	4	4	1	0	1	0	0	0	0	0	0	0	0	306
20.0	264	35	3	2	0	0	1	1	0	0	0	0	0	0	0	306
21.0	266	36	2	3	0	0	0	1	0	0	0	0	0	0	0	308
22.0	265	32	3	3	1	1	1	1	0	0	0	0	0	0	0	307
23.0	265	32	2	4	0	0	2	1	0	0	0	0	0	0	0	306
24.0	265	33	1	2	1	2	1	1	0	0	0	0	0	0	0	306
TOTALS	5938	911	128	105	55	36	55	33	18	11	3	1	0	0	0	

1 SO2 VALUES LESS THAN 0.000

0 SO2 VALUES LARGER THAN 500.0

TABLE 16. FREQUENCY DISTRIBUTION OF SO_2 VS. HOUR FROM 76286 TO 77273, HOCKEY SITE
(ROW & COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS)

SO_2 ($\mu g/m^3$)

HOUR	5.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0	80.0	100.0	150.0	200.0	300.0	500.0	TOTALS
1.0	221	60	13	5	4	9	5	4	1	5	0	1	0	0	0	330
2.0	221	58	19	6	3	5	7	4	4	2	1	1	0	0	0	331
3.0	212	64	14	9	5	12	2	3	2	2	1	1	1	1	0	329
4.0	211	65	11	6	9	6	3	6	2	3	0	4	0	0	0	329
5.0	216	60	17	12	4	7	2	1	3	1	1	1	0	0	1	326
6.0	221	54	19	16	8	2	3	1	2	2	0	0	0	0	0	327
7.0	221	53	15	14	6	5	5	5	1	2	0	0	0	0	0	327
8.0	215	57	16	10	7	8	7	2	0	2	1	1	0	0	0	326
9.0	215	47	17	9	9	9	2	3	5	1	1	1	1	1	0	321
10.0	220	38	17	10	9	11	3	5	4	4	2	2	0	0	0	325
11.0	217	45	19	8	12	5	7	5	3	1	1	1	0	0	0	324
12.0	226	39	23	7	5	11	6	4	2	0	1	0	0	0	0	326
13.0	225	46	20	11	6	4	8	3	0	0	1	0	0	0	0	324
14.0	235	44	19	8	6	5	3	1	0	0	0	0	0	0	0	321
15.0	242	42	15	13	3	5	4	1	1	0	0	0	0	0	0	326
16.0	252	40	14	7	7	2	2	1	0	1	0	0	0	0	0	326
17.0	259	41	9	7	4	4	2	1	1	0	0	0	0	0	0	328
18.0	264	35	11	9	1	4	3	3	0	0	0	0	0	0	0	329
19.0	251	43	13	6	6	3	1	2	1	1	0	0	0	0	0	329
20.0	248	36	14	14	5	4	3	3	1	1	0	0	0	0	0	329
21.0	234	41	22	15	5	4	4	4	1	0	0	0	0	0	0	330
22.0	237	44	12	14	7	3	5	2	0	0	0	0	0	0	0	330
23.0	231	50	13	9	6	7	4	4	2	0	1	0	0	0	0	330
24.0	223	51	21	7	9	5	5	3	2	2	0	1	1	0	0	330
TOTALS	5505	1171	392	232	142	145	98	71	38	30	11	14	3	2	1	

0 SO2 VALUES LESS THAN 0.000   0 SO2 VALUES LARGER THAN 500.0

TABLE 17. FREQUENCY DISTRIBUTION OF SO_2 VS. HOUR FROM 76286 TO 77273, LAMBERT SITE

(ROW & COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS)

SO_2 ($\mu g/m^3$)

HOUR	5.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0	80.0	100.0	150.0	200.0	300.0	500.0	TOTALS
1.0	192	11	9	3	2	0	0	0	0	0	0	0	0	0	0	217
2.0	193	8	9	7	1	0	0	0	0	0	0	0	0	0	0	218
3.0	197	12	5	4	0	1	0	0	0	0	0	0	0	0	0	219
4.0	199	10	4	4	3	0	0	0	0	0	0	0	0	0	0	220
5.0	192	12	4	2	3	2	0	0	0	0	0	0	0	0	0	215
6.0	195	7	7	1	4	2	1	0	0	0	0	0	0	0	0	217
7.0	186	11	8	5	3	0	2	0	0	0	0	0	0	0	0	215
8.0	186	13	3	6	2	3	0	0	0	0	0	0	0	0	0	213
9.0	182	15	7	4	2	1	1	0	0	0	0	0	0	0	0	212
10.0	169	15	9	5	7	3	1	2	0	1	0	0	0	0	0	212
11.0	159	17	11	9	4	3	2	2	1	1	0	0	0	0	0	209
12.0	164	19	7	10	3	1	3	0	0	3	0	0	0	0	0	210
13.0	165	18	13	7	4	2	0	1	0	0	0	0	0	0	0	210
14.0	175	10	12	7	1	2	0	0	0	0	0	0	0	0	0	207
15.0	186	12	4	7	2	1	0	0	0	0	0	0	0	0	0	212
16.0	197	5	11	6	1	0	0	0	0	0	0	0	0	0	0	220
17.0	198	12	4	5	1	0	0	1	0	0	0	0	0	0	0	221
18.0	201	7	8	3	2	0	0	0	0	0	0	0	0	0	0	221
19.0	200	8	6	3	2	1	2	0	0	0	0	0	0	0	0	222
20.0	199	8	4	8	1	2	0	0	0	0	0	0	0	0	0	222
21.0	193	8	7	8	2	2	0	0	0	0	0	0	0	0	0	220
22.0	192	12	10	0	4	2	1	0	0	0	0	0	0	0	0	221
23.0	188	16	12	2	4	0	1	0	0	0	0	0	0	0	0	223
24.0	193	11	10	2	2	1	0	0	0	0	0	0	0	0	0	219
TOTALS	4501	277	184	118	60	29	14	6	1	5	0	0	0	0	0	

0 SO2 VALUES LESS THAN 0.000   0 SO2 VALUES LARGER THAN 500.0

TABLE 18. FREQUENCY DISTRIBUTION OF SO_2 VS. HOUR FROM 76286 TO 77273, JOHNSON SITE (ROW & COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS)

SO_2 ($\mu g/m^3$)

HOUR	5.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0	80.0	100.0	150.0	200.0	300.0	500.0	TOTALS
1.0	135	39	32	17	8	3	6	3	1	1	2	0	1	0	0	248
2.0	147	35	21	15	9	6	8	2	1	2	1	2	0	0	0	249
3.0	136	25	45	16	6	4	6	3	0	2	2	1	1	0	0	247
4.0	130	32	41	17	9	6	3	1	1	1	2	1	1	0	0	247
5.0	139	23	41	20	7	4	4	1	0	3	1	1	0	0	0	246
6.0	137	21	44	21	7	7	3	2	1	1	2	1	0	0	0	247
7.0	131	26	41	19	11	3	6	3	0	2	2	1	0	0	0	245
8.0	128	24	42	18	11	6	6	2	1	1	1	1	0	0	0	245
9.0	127	36	39	14	11	3	4	4	0	2	1	1	0	0	0	242
10.0	124	48	38	20	7	1	2	3	0	4	1	0	0	0	0	247
11.0	125	49	34	20	4	2	5	3	1	2	0	1	0	0	0	246
12.0	146	49	22	12	9	2	9	2	0	2	0	0	0	0	0	252
13.0	155	44	27	9	4	3	4	4	0	1	0	0	0	0	0	251
14.0	162	52	19	8	2	2	3	2	0	1	0	0	0	0	0	251
15.0	174	44	16	10	2	0	2	3	1	0	1	0	0	0	0	253
16.0	172	43	21	9	1	3	2	1	0	2	0	0	0	0	0	254
17.0	178	41	26	6	1	0	3	1	1	1	0	0	0	0	0	258
18.0	170	51	19	9	3	2	2	1	0	1	0	0	0	0	0	258
19.0	160	57	19	13	2	3	2	2	0	1	0	0	0	0	0	259
20.0	156	51	23	14	5	2	3	1	1	1	0	0	0	0	0	257
21.0	151	38	34	13	9	2	3	1	0	1	0	0	0	0	0	256
22.0	145	41	31	18	4	3	5	1	1	0	1	0	0	0	0	256
23.0	146	35	34	22	4	1	4	3	1	2	1	1	1	0	0	255
24.0	138	37	33	21	6	1	2	2	1	3	1	0	0	1	0	249
TOTALS	3511	947	742	364	187	63	91	56	12	37	21	11	4	1	0	

0 SO2 VALUES LESS THAN 0.000 0 SO2 VALUES LARGER THAN 500.0

TABLE 19. FREQUENCY DISTRIBUTION OF SO_2 VS. HOUR FROM 76286 TO 77273, KENTS SITE (ROW & COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS)

HOUR	SO_2 ($\mu g/m^3$) 5.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0	80.0	100.0	150.0	200.0	300.0	500.0	TOTALS
1.0	305	9	2	2	1	0	3	1	0	0	0	0	0	0	0	323
2.0	304	7	2	4	2	1	1	0	2	0	0	0	0	0	0	323
3.0	304	7	2	2	2	3	0	1	0	0	0	0	1	0	0	322
4.0	300	9	6	2	0	1	1	1	2	0	0	0	0	0	0	322
5.0	296	7	6	1	2	0	2	3	1	1	0	0	0	0	0	319
6.0	299	5	4	4	1	0	4	0	0	2	1	0	0	0	0	320
7.0	292	10	6	3	1	2	1	2	0	2	0	0	0	0	0	319
8.0	296	8	5	4	2	1	2	0	2	0	0	0	0	0	0	320
9.0	291	10	3	4	3	1	1	1	0	0	0	1	0	0	0	315
10.0	284	12	5	6	2	2	1	1	3	0	0	0	0	0	0	316
11.0	278	16	7	3	2	0	4	2	4	0	0	0	0	0	0	316
12.0	274	18	11	4	4	1	1	2	0	0	0	1	0	0	0	316
13.0	281	21	7	2	4	1	1	1	0	0	0	0	1	0	0	319
14.0	288	13	11	1	2	0	2	0	0	0	0	0	0	0	0	317
15.0	294	13	9	1	0	1	1	0	0	0	0	0	0	0	0	319
16.0	302	10	7	3	1	0	0	0	0	0	0	0	0	0	0	323
17.0	303	10	6	2	2	0	0	0	0	0	0	0	0	0	0	323
18.0	304	12	4	2	1	0	0	1	0	0	0	0	0	0	0	324
19.0	303	11	4	4	0	1	0	1	0	0	0	0	0	0	0	324
20.0	305	9	5	3	1	1	0	1	0	0	0	0	0	0	0	325
21.0	308	4	4	3	2	3	0	1	0	0	0	0	0	0	0	325
22.0	303	9	4	5	0	0	3	0	0	0	0	0	0	0	0	324
23.0	304	7	5	3	2	0	2	1	0	0	0	0	0	0	0	324
24.0	305	8	5	1	1	2	1	2	0	0	0	0	0	0	0	325
TOTALS	7123	245	130	69	38	21	31	22	14	5	1	2	2	0	0	

0 SO2 VALUES LESS THAN 0.000

0 SO2 VALUES LARGER THAN 500.0

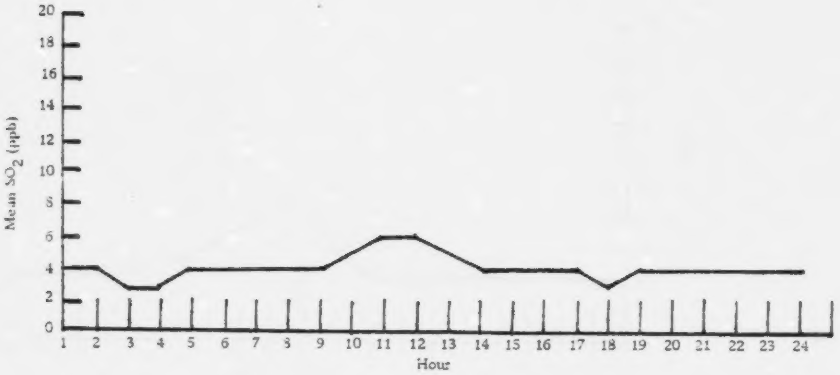

Figure 3. Diurnal variation of mean SO_2 concentrations at Lambert.

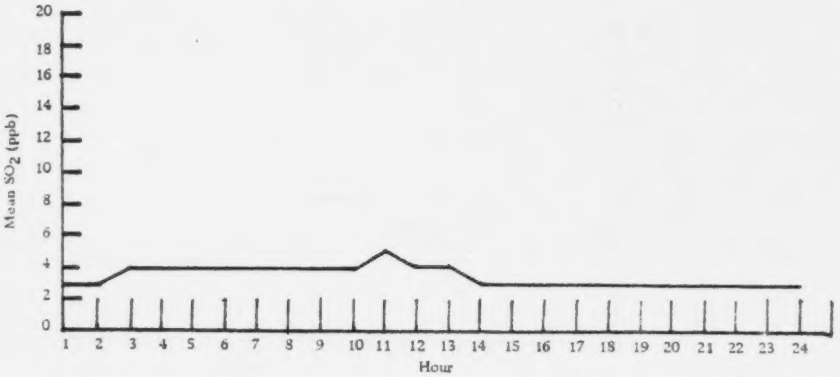

Figure 4. Diurnal variation of mean SO_2 concentrations at Kents.

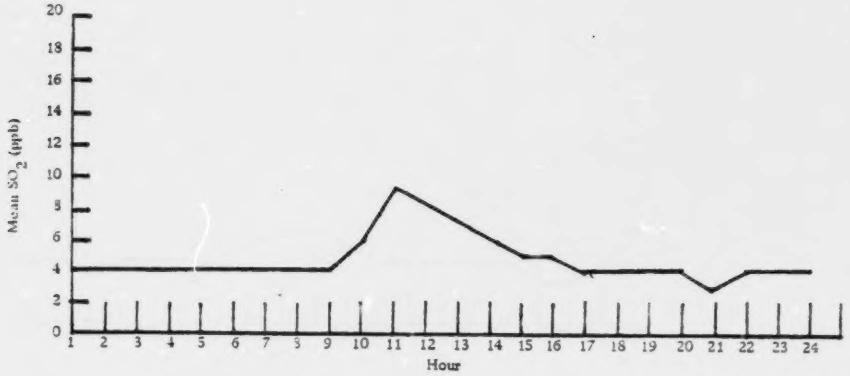

Figure 5. Diurnal variation of mean SO_2 concentrations at Nashs.

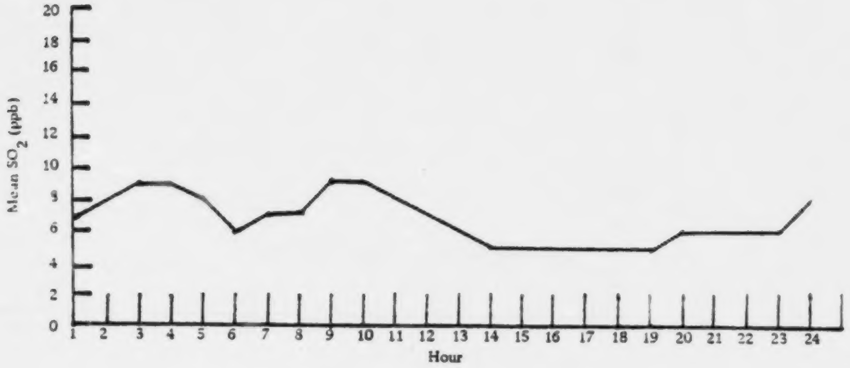

Figure 6. Diurnal variation of mean SO_2 concentrations at Hockey.

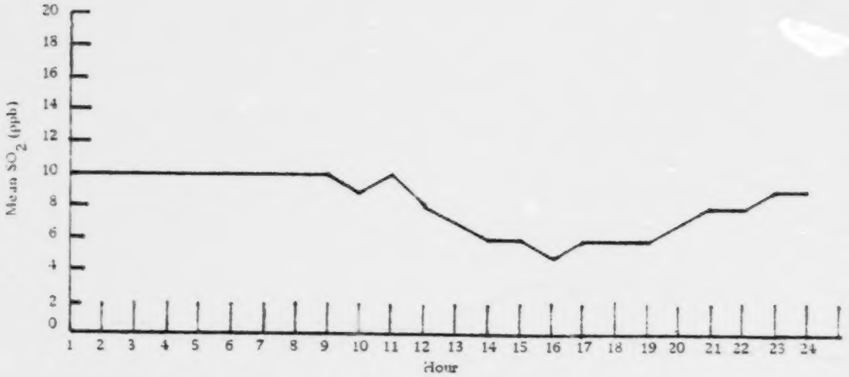

Figure 7. Diurnal variation of mean SO_2 concentrations at Johnson.

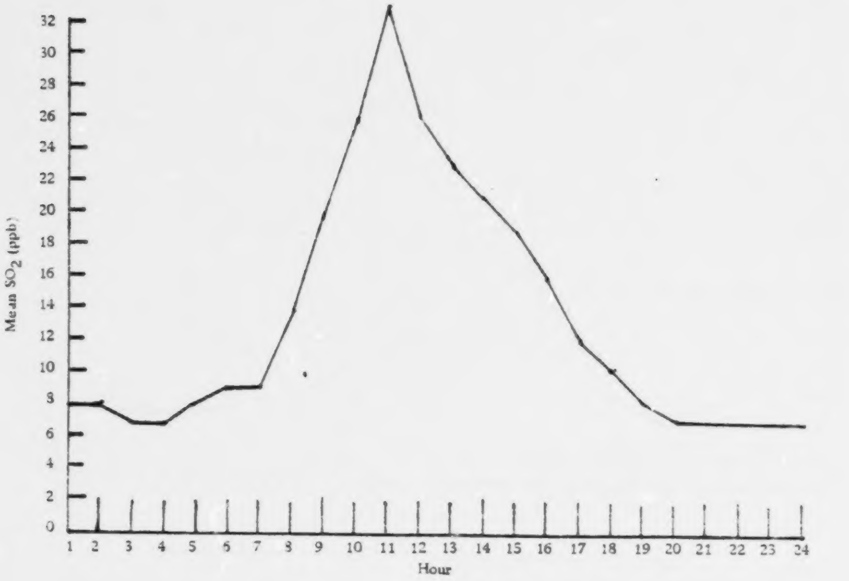

Figure 8. Diurnal variation of mean SO_2 concentrations at Tower.

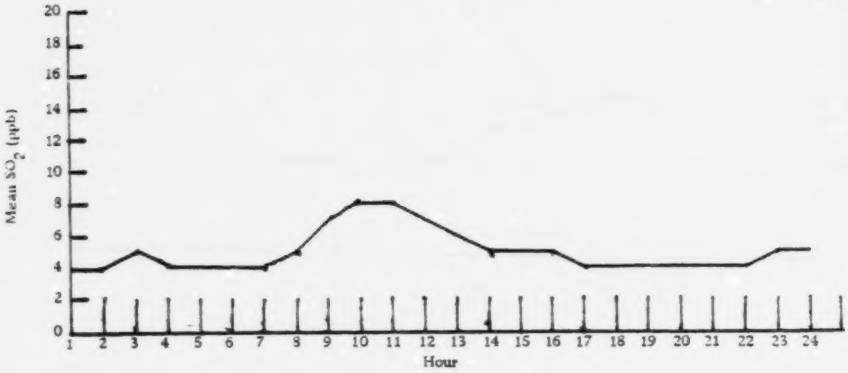

Figure 9. Diurnal variation of mean SO_2 concentrations at Munsey.

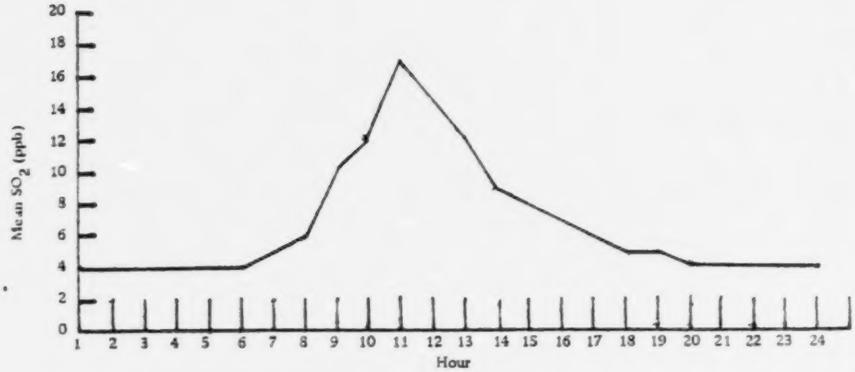

Figure 10. Diurnal variation of mean SO_2 concentrations at Castlewood.

These results indicate that during the vast majority of the time the power plant plume was not impacting a particular station. Both Johnson, located 5.76 km from the plant, and the closest station to the plant (Tower) recorded the lowest frequency of extremely low SO_2 concentrations (less than 10 ppb). This indicates that either the power plant plume impacted these stations the most frequently or other smaller sources also affected the stations. The Moss No. 3 Coal Preparation Plant which burns a small amount of low-sulfur coal is located 0.84 km WNW of the Tower station and may have a small impact on SO_2 concentrations at this site. However, no known sources of SO_2 existed in the immediate vicinity of the Johnson station.

Frequency distributions of SO_2 concentrations versus various meteorological parameters were produced for the entire monitoring period and also on an individual season basis. The relationships between the concentration data and the meteorological conditions are discussed in Section 8. Differences between seasons of the year have been noted in the distributions, however. At five stations (Johnson, Kents, Lambert, Munsey and Nashs) the season with the greatest frequency of high SO_2 concentrations (greater than 100 ppb) was winter. The Castlewood results showed the highest frequency in spring, while Tower and Hockey had their highest frequency of high SO_2 concentrations in summer and fall.

AMBIENT POLLUTION CONCENTRATIONS - MOBILE VAN

The mobile ground sampling was conducted using a van equipped to measure SO_2, NO_x, NO, NO_2, and O_3, as well as wind speed, direction, and temperature. During the early portion of the field study the van was used in a moving mode searching for the plume. After the plume was located, stationary samples were taken. Beginning in March, 1977, all sampling by the van was performed in the stationary mode. Prior to the departure of the van from the plant on a given day, stationary sampling locations were chosen based on the expected position of the plume estimated by the use of the wind direction at the Hockey 30 m level. Positions were changed if winds shifted during the day. A total of 866 hours and 22 minutes of sampling was performed by the van. Of this total, 628 hours and 45 minutes were performed in the stationary mode and 237 hours and 37 minutes were conducted with the van in motion.

Table 20 presents the mean pollutant concentrations for all the stationary (fixed) samples, all the moving samples, and for all samples combined. For each pollutant these means are greater than any of the mean pollutant concentrations computed for the eight fixed stations, indicating that the van was located under the plume more often than were any of the fixed stations. The means for the stationary sampling are greater than those for the moving sampling for both SO_2 and NO_x indicating that the van probably was under the plume more often during the stationary samples than during the moving samples or that the stationary samples were more often taken nearer the plume centerline.

TABLE 20. MEAN POLLUTANT CONCENTRATIONS FOR MOBILE VAN DATA

	MEAN CONCENTRATIONS		
MEAN VALUES	FIXED SAMPLING	MOVING SAMPLING	TOTAL SAMPLING
SO2	37.46	28.76	32.71
NOX	57.51	45.11	53.63
NO2	24.47	19.18	22.98
NO	33.92	32.58	33.55
O3	24.02	22.36	23.51
TOTAL SAMPLING TIME:	628 HOURS 45 MINS	237 HOURS 37 MINS	866 HOURS 22 MINS

NOTE: UNITS = PPB

The number of significant SO_2 and NO_x measurements also illustrate the usefulness of the van in making plume measurements. Tables 21 through 25 present frequency distributions for the five pollutants for the stationary sampling events. Only 49.8% of the samples had mean SO_2 concentrations less than approximately 20 ppb, whereas the percentage for the fixed station (Tower) with the least number of hourly average SO_2 concentrations less than 20 ppb was 83.5%. Therefore, a power plant plume can be detected at the ground considerably more often by a van than by a fixed station.

The mobile van data were also analyzed through the construction for each pollutant of two-way tables stratifying the stationary sample data by the following three methods: (1) distance from the plant versus elevation; (2) hour versus elevation; and (3) distance from the plant versus direction from the plant. These tables, presented in Appendix A, give the mean concentration and number of samples for each combination of distance and elevation, hour and elevation, and distance and direction. The category with the highest mean SO_2 concentration was 0.0 to 0.5 km and 457-488 m MSL (1500-1600 feet MSL) (i.e., very close to the plant). These concentrations may have resulted from downwash of the plume near the plant caused by a nearby upwind ridge. Seventy-five percent of the fixed samples were taken from 3 km to 10 km from the plant. The most frequent sampling location was the category 3 to 5 km from the plant and 518-579 m MSL (1700 to 1900 feet MSL). Most of the sampling was performed between 0800 and 1800 local standard time. At distances greater than 5 km the direction classes 30° to 60° and 60° to 90° contained the highest mean SO_2 concentrations. This result may be caused by the prevailing southwesterly flow over the region.

The van data are also useful in examining the NO/NO_x ratio as a function of distance from the plant. Ground-level NO concentrations are much higher than NO_2 close to the plant. In the 0.0 to 0.5 km distance range and 457-488 m MSL (1500 to 1600 feet MSL) category, the mean NO concentration was 410 ppb while the mean NO_2 concentration was 73 ppb, giving a mean ratio of 5.6. In the 2 to 3 km range the mean NO to NO_2 concentrations give a ratio of 0.8 in the 518-579 m MSL (1700 to 1900 feet MSL) elevation category, for which there are 44 measurements. The NO to NO_2 ratio seems to be leveled off at about the 0.8 level for the remainder of the travel distances, suggesting that the reaction rate has greatly slowed down or reached some sort of equilibrium. Table 26 presents the average ozone concentrations for each of 9 distance ranges and the number of cases in each range. There is the suggestion of evidence of ozone depletion in the plume at the 1 to 2 km and 2 to 3 km distance ranges as these ranges show lower O_3 concentrations than both shorter and longer distances from the plant.

TABLE 21. FREQUENCY DISTRIUBTION OF SO_2 CONCENTRATIONS MEASURED IN VAN WHILE IN STATIONARY MODE

UNITS: PPB

CONCENTRATION RANGES		FREQUENCY	PERCENT
	<-12.33	1	0.1
-12.33,	4.27	171	14.3
4.27,	20.86	426	35.6
20.86,	37.46	238	19.9
37.46,	54.05	145	12.1
54.05,	70.64	93	7.8
70.64,	87.24	48	4.0
87.24,	103.83	23	1.9
103.83,	120.42	10	0.8
120.42,	137.02	5	0.4
137.02,	153.61	3	0.3
153.61,	170.20	6	0.5
170.20,	186.80	6	0.5
186.80,	203.39	3	0.3
203.39,	219.98	0	0.0
219.98,	236.58	0	0.0
	>236.58	20	1.7

TABLE 22. FREQUENCY DISTRIBUTION OF NO_X CONCENTRATIONS MEASURED IN VAN WHILE IN STATIONARY MODE

UNITS: PPB

CONCENTRATION RANGES		FREQUENCY	PERCENT
	<-17.13	0	0.0
-17.13,	20.19	449	41.4
20.19,	57.51	369	34.0
57.51,	94.83	123	11.3
94.83,	132.15	64	5.9
132.15,	169.46	38	3.5
169.46,	206.78	12	1.1
206.78,	244.10	8	0.7
244.10,	281.42	0	0.0
281.42,	318.74	3	0.3
318.74,	356.06	2	0.2
356.06,	393.38	3	0.3
393.38,	430.70	2	0.2
430.70,	468.02	0	0.0
468.02,	505.34	0	0.0
	>505.34	11	1.0

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TABLE 23. FREQUENCY DISTRIBUTION OF NO_2 CONCENTRATIONS MEASURED IN VAN WHILE IN STATIONARY MODE

UNITS: PPB

CONCENTRATION RANGES		FREQUENCY	PERCENT
	<-3.58)	0	0.0
-3.58,	3.43	120	12.7
3.43,	10.45	206	21.9
10.45,	17.46	160	17.0
17.46,	24.47	109	11.6
24.47,	31.49	101	10.7
31.49,	38.50	73	7.7
38.50,	45.51	39	4.1
45.51,	52.52	35	3.7
52.52,	59.54	21	2.2
59.54,	66.55	22	2.3
66.55,	73.56	13	1.4
73.56,	80.58	10	1.1
80.58,	87.59	10	1.1
87.59,	94.60	4	0.4
94.60,	101.61	5	0.5
101.61,	108.63	3	0.3
	>108.63	11	1.2

TABLE 24. FREQUENCY DISTRIBUTION OF NO CONCENTRATIONS MEASURED IN VAN WHILE IN STATIONARY MODE

UNITS: PPB

CONCENTRATION RANGES		FREQUENCY	PERCENT
	<-32.34	0	0.0
-32.34,	0.79	84	8.8
0.79,	33.92	690	72.0
33.92,	67.05	102	10.6
67.05,	100.17	40	4.2
100.17,	133.30	17	1.8
133.30,	166.43	3	0.3
166.43,	199.56	2	0.2
199.56,	232.68	5	0.5
232.68,	265.81	0	0.0
265.81,	298.94	2	0.2
298.94,	332.07	2	0.2
332.07,	365.19	1	0.1
365.19,	398.32	0	0.0
398.32,	431.45	1	0.1
	<431.45	9	0.9

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TABLE 25. FREQUENCY DISTRIBUTION OF O_3 CONCENTRATIONS MEASURED IN VAN WHILE IN STATIONARY MODE

UNITS: PPB

CONCENTRATION RANGES	FREQUENCY	PERCENT
-3.43	0	0.0
-3.43, 2.06	183	16.6
2.06, 7.55	131	11.9
7.55, 13.04	117	10.6
13.04, 18.53	110	10.0
18.53, 24.02	97	8.8
24.02, 29.51	82	7.4
29.51, 35.00	96	8.7
35.00, 40.49	71	6.4
40.49, 45.98	48	4.4
45.98, 51.47	44	4.0
51.47, 56.96	32	2.9
56.96, 62.45	18	1.6
62.45, 67.94	18	1.6
67.94, 73.43	18	1.6
73.43, 78.92	9	0.8
78.92, 84.41	8	0.7
84.41, 89.90	9	0.8
89.90	12	1.1

TABLE 26. OZONE CONCENTRATIONS VERSUS DISTANCE FROM PLANT FOR MOBILE VAN DATA

Distace Range (km)	Average O_3 Concentration (ppb)	Number of Cases
0.0 - 0.5	34	29
0.5 - 1.0	25	4
1.0 - 2.0	16	11
2.0 - 3.0	11	81
3.0 - 5.0	22	447
5.0 - 7.0	27	236
7.0 - 10.0	28	175
10.0 - 15.0	29	99
> 15.0	19	21

CONCLUSIONS

Statistics produced from the pollutant monitoring data for the eight fixed stations show generally low annual-average concentrations of SO_2 and NO_x. The ten highest individual hourly values of SO_2 and NO_x at the non-ridgetop stations show a tendency for the highest concentrations to occur in the late morning, suggesting that fumigation of the plume during inversion breakup is an important process. The diurnal variation pattern of the mean SO_2 concentration at these stations also supports this hypothesis. The mobile van was capable of recording plume impact with greater frequency than did any of the fixed monitoring stations. The van measurements of NO and NO_2 are useful in studying the NO/NO_2 ratio as a function of distance from the plant. This ratio decreased through the first 2 to 3 km from the plant and then leveled off at approximately a value of 0.8.

SECTION 6

ANALYSIS OF PLUME STRUCTURE

Except in the situation where two or more fixed stations are located near enough to each other and at different elevations such that both are affected by the power plant plume simultaneously, fixed stations at ground level reveal little concerning the structure of the plume. In the Clinch River monitoring network two fixed stations were situated such that some plume structure information could be obtained. These were the Hockey and Munsey stations, both located almost on a direct line from the plant. During operation of the mobile van, useful data for plume definition were available for three points. Results of the analysis of the Hockey/Munsey relationship appear in Section 8, both from a statistical approach and from individual case studies.

The most useful information concerning plume position and structure is available from the plume measurements taken by helicopter. The airborne observations were gathered during two intensive study periods - November 8 to 17, 1976, and July 20 to 28, 1977. The July 1977 data, however, are of much greater value as the entire data set for July is composed of plume cross sections flown between specific landmarks. However, these data require extensive processing to determine the position and dimensions of the plume.

DATA PREPARATION

The helicopter data on the Clinch River Data Tape* contains a great degree of detail which must be processed and interpreted to determine representative cloud dimension parameters such as the Gaussian plume dimensions σ_y and σ_z. Based on notes taken during the flights a set of plume traverse endpoints was compiled. Coordinates for each of these endpoints were obtained from U.S. Geological Survey maps. The helicopter data were recorded as scans of the instruments at a rate of between 4 and 5 scans per second.

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* The data from the Clinch River field study is available from the National Technical Information Service on magnetic tape as EPA Report Number EPA-600/7/79-010b.

Each scan became a separate record on tape identified by a time. Based on the coordinate and time information, x and y coordinates had been computed for each scan. An elevation above sea level was also associated with each record. The first step in processing the scan data was to average the data over periods comparable to the response time of the instrument and to adjust the data in time and space to account for the instrument response and lag times. The lag time is the time required to pump the sample gas into the instruments from the base of the helicopter. The data were separated into identifiable cross sections. A cross section was defined as a group of traverses flown at several different altitudes between a set of fixed endpoints at a particular distance downwind of the power plant (see Figure 11).

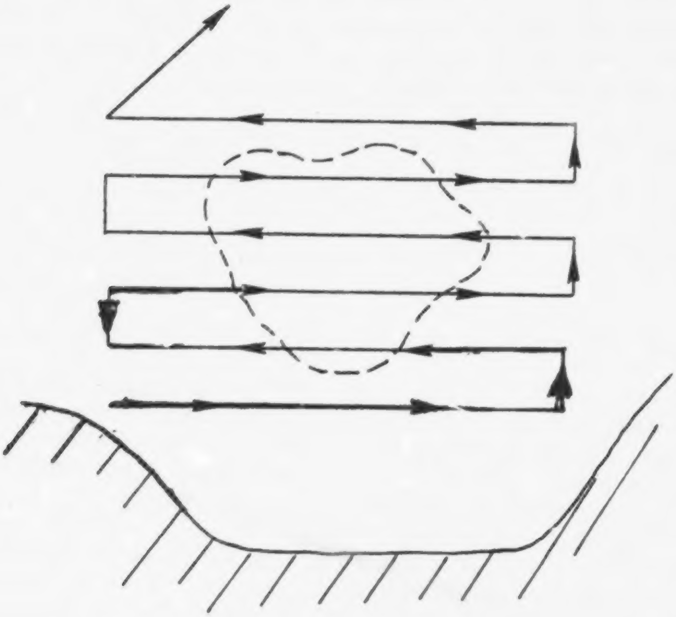

Figure 11. Representative helicopter flight path at fixed distance from the power plant.

Twenty-four plume cross sections were identified in the July 1977 helicopter data. Table 27 summarizes the times, altitudes and number of traverses for each cross section. The original scan data in each cross section were averaged over each 9 successive data points to obtain a value approximately every 2 seconds. The following instrument response time correction was applied to these values:

$$C_r(t) = C_i(t) + \alpha \frac{dC_i(t)}{dt} + \beta \frac{d^2C_i(t)}{dt^2}$$

where $C_r(t)$ is the real pollutant concentration at time t, $C_i(t)$ is the observed concentration at time t, and α and β are constants related to the time constant of the instrument. Based on information from the manufacturers the following α and β values were used:

	SO_2	NO_x, NO
α	4.9	2.0
β	2.56	0.0

No instrument response adjustment was necessary for the ozone data.

The corrected cross-section data were plotted and examined for any inconsistencies or problems. It was noted that in portions of some cross-sections the peak SO_2, NO_x and NO concentrations as well as the minimum O_3 concentrations for each traverse appeared to move back and forth along the crosswind axis with each successive traverse. In addition, the SO_2 peak always occurred after the NO_x peak. The lag of SO_2 peak after the NO_x peak averaged 4.5 seconds for all traverses except those labeled as events 749-783, for which the time difference averaged 10.5 seconds. It was hypothesized that this lag was caused by the delay in SO_2 gas reaching the instrument which had a smaller flow rate than the NO_x instrument. The SO_2 analyzer drew 283 cm^3/min, the NO_x-NO analyzer drew 1000 cm^3/min, and the ozone analyzer drew 275 cm^3/min. Using these flow rates and the diameters and lengths of the tubes, the times required for the gases to reach their respective instruments were computed. For SO_2 this computation resulted in 5.91 seconds; for NO_x and NO the lag time was 1.67 seconds, while for O_3 it was only 0.71 seconds. The difference between the SO_2 lag and the NO_x lag was 4.24 seconds which is very close to the 4.5 seconds difference between the SO_2 and NO_x peaks observed in the data. The much larger difference between the times of the SO_2 and NO_x peaks for events 749-783 was the

TABLE 27. SUMMARY OF HELICOPTER CROSS SECTIONS FOR JULY 1977

Cross Section Number	Date	Begin time	End time	Begin event	End event	Begin altitude (m)MSL	End altitude (m)MSL	Number of Traverses
1	July 23	0956	1006	408	412	945	1006	3
2	July 23	1022	1037	416	422	762	854	4
3	July 23	1038	1048	424	428	823	762	3
4	July 23	1403	1426	431	445	884	671	8
5	July 23	1427	1510	447	475	701	1128	15
6	July 24	0837	0856	501	511	762	915	6
7	July 24	0915	0947	519	533	793	1006	8
8	July 24	1007	1023	539	543	854	732	3
9	July 24	1202	1304	545	578	701	1220	17
10	July 24	1306	1353	580	608	1159	671	15
11	July 24	1436	1558	610	650	701	1311	21
12	July 24	1607	1621	654	662	915	671	5
13	July 26	1041	1135	701	725	701	1067	13
15	July 26	1510	1619	749	785	762	1220	18
17	July 26	1643	1659	793	803	1098	793	6
18	July 27	0910	1109	805	861	732	1585	29
20	July 27	1308	1336	868	878	1524	1220	6
22	July 27	1341	1422	880	898	1220	732	10
23	July 27	1426	1502	900	914	793	1220	8
24	July 27	1616	1733	916	946	793	1341	16
25	July 27	1737	1808	948	968	1341	732	11
26	July 28	0919	1039	970	019	732	1463	25
28	July 28	1213	1301	023	045	823	1494	12
29	July 28	1304	1408	047	077	1494	793	16

result of the use of a new transducer in the SO_2 analyzer which was initially very slow in response.

The cross section data were modified in the following manner to account for the lag involved in the gas reaching the instruments. For all events except 749-783 the SO_2 data was moved 6 seconds (3 records) back in time, while the NO_x, NO and NO_2 data for all traverses were moved 2 seconds (1 record) back. No adjustment was made to the O_3 data. For events 749-783 the SO_2 data was moved 12 seconds back (6 records) to account for both the additional instrument response time and the regular 6 second lag time.

Nineteen of the 24 cross sections were observed between two end points; however, Cross Sections #18, #20, #24, #26, and #28 are composed of traverses along more than one line (different sets of checkpoints). Shifting winds during the cross section necessitated changes in the flight path. Cross Sections #18, #24, #26, and #28 were flown along three paths, while Cross Section #20 utilized two traverse paths. Figures 12 through 16 depict the multiple-path cross sections and also show the mean Hockey 30 m wind direction for the period of the cross section.

After the final adjusted cross section data were plotted, considerable movement of the position of the peak concentrations from traverse to traverse was still evident in portions of some cross sections. The center of mass for each traverse was computed, and the same phenomenon was observed in these positions. Movements of the center of mass ranging from 200 to 1000 m along the cross-wind axis were evident between successive traverses. Table 28 presents the variation in position of the center of mass from traverse to traverse for three cross sections. It was hypothesized that the cause of this phenomenon was primarily the meander of the wind direction during successive traverses which make up the cross section. Two approaches were used to explore this idea. The first approach was as follows. The variation in wind direction between successive Hockey 30 m wind data read outs (2 minutes apart) were reviewed for two of the cases (Cross Sections #4 and #6). The range of the 2-minute wind directions recorded at the Hockey station at the 30 m level (approximately the plume height) during the cross section either equaled or exceeded the range of directions defined by the range of the positions of the peak SO_2 concentrations of the individual traverses (see Figures 17, 18). In these figures the arrows represent the two-minute wind directions during the cross section while the tic marks on the cross section line represent the locations of the SO_2 peaks of the traverses.

The second approach for analysis of the plume shift phenomenon involved determining the plume centerline position along the traverse path as defined by the calculated plume configuration at successive 2-minute intervals. The plume configuration is determined through the use of Hockey 30 m level 2 minute wind data. A computer program was written to advect every two minutes each previous two-minute wind vector, representing

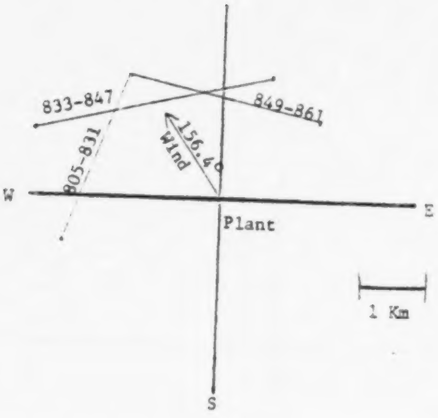
N
833-847
849-861
805-831
156.4°
Wind
W
E
Plant
1 Km
S

Figure 12. Traverse paths for cross section #18 and event numbers

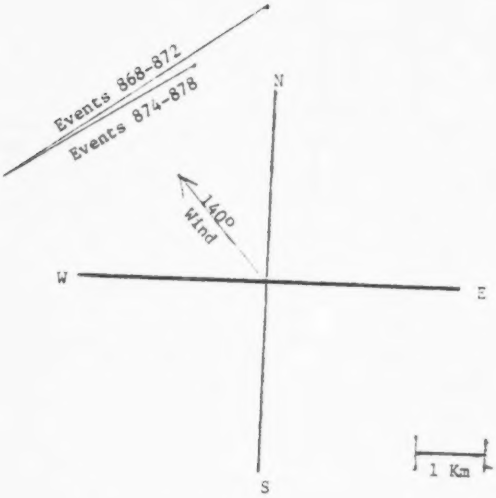
Events 868-872
Events 874-878
N
140°
Wind
W
E
1 Km
S

Figure 13. Traverse paths for cross section #20 and event numbers

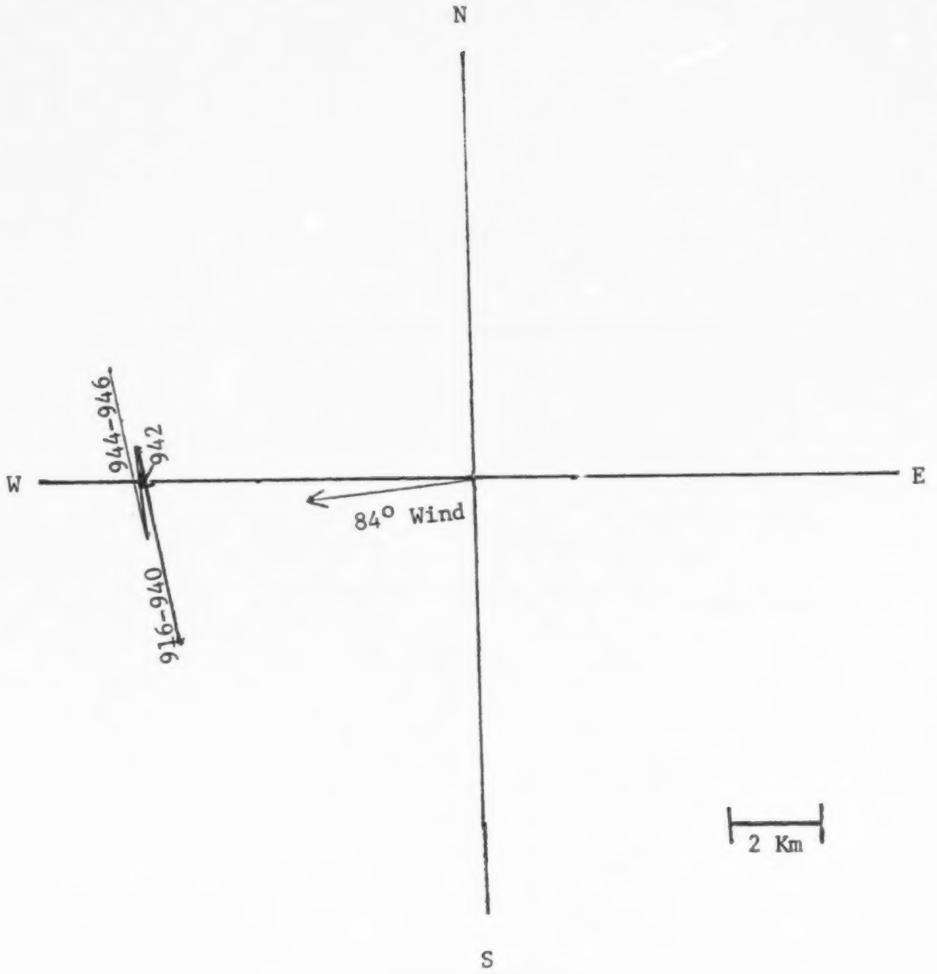
N
W
E
S
944-946
942
916-940
84° Wind
2 Km

Figure 14. Traverse paths for cross section #24 and event numbers

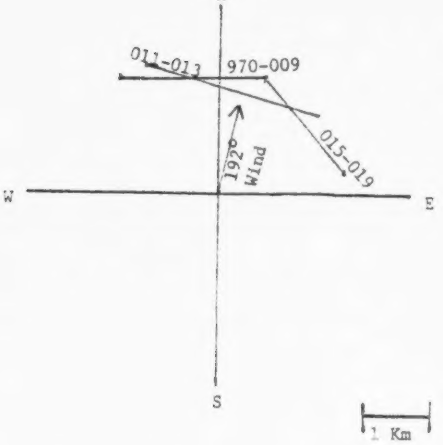
N
011-013
970-009
015-019
192°
Wind
W
E
S
1 Km

Figure 15. Traverse paths for cross section #26 and event numbers

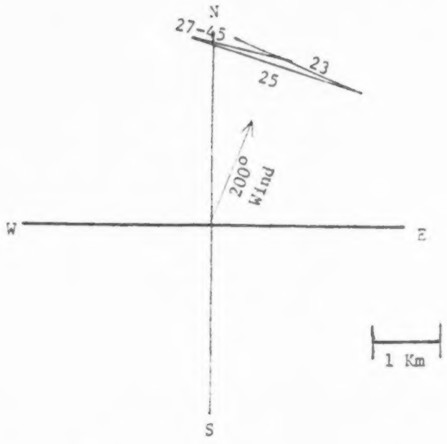
N
27-45
23
25
200°
Wind
W
E
1 Km
S

Figure 16. Traverse paths for cross section #28 and event numbers

TABLE 28. LOCATIONS OF CENTER OF MASS OF INDIVIDUAL TRAVERSES

Cross section number	Altitude (m MSL)	Distance of center of mass from endpoint (m)
4	883	960
	853	1050
	823	944
	793	1030
	762	922
	731	1107
	701	887
	671	1014
6	762	1493
	792	1354
	823	1539
	853	1439
	883	1389
	914	1505
15	762	1517
	792	1759
	823	1327
	853	1669
	883	1343.
	914	1340
	883	1931
	914	1389
	914	2020
	944	1339
	975	1429
	1005	1655
	1036	1625
	1066	1618
	1097	1873
	1127	1696
	1158	2117
	1188	1333

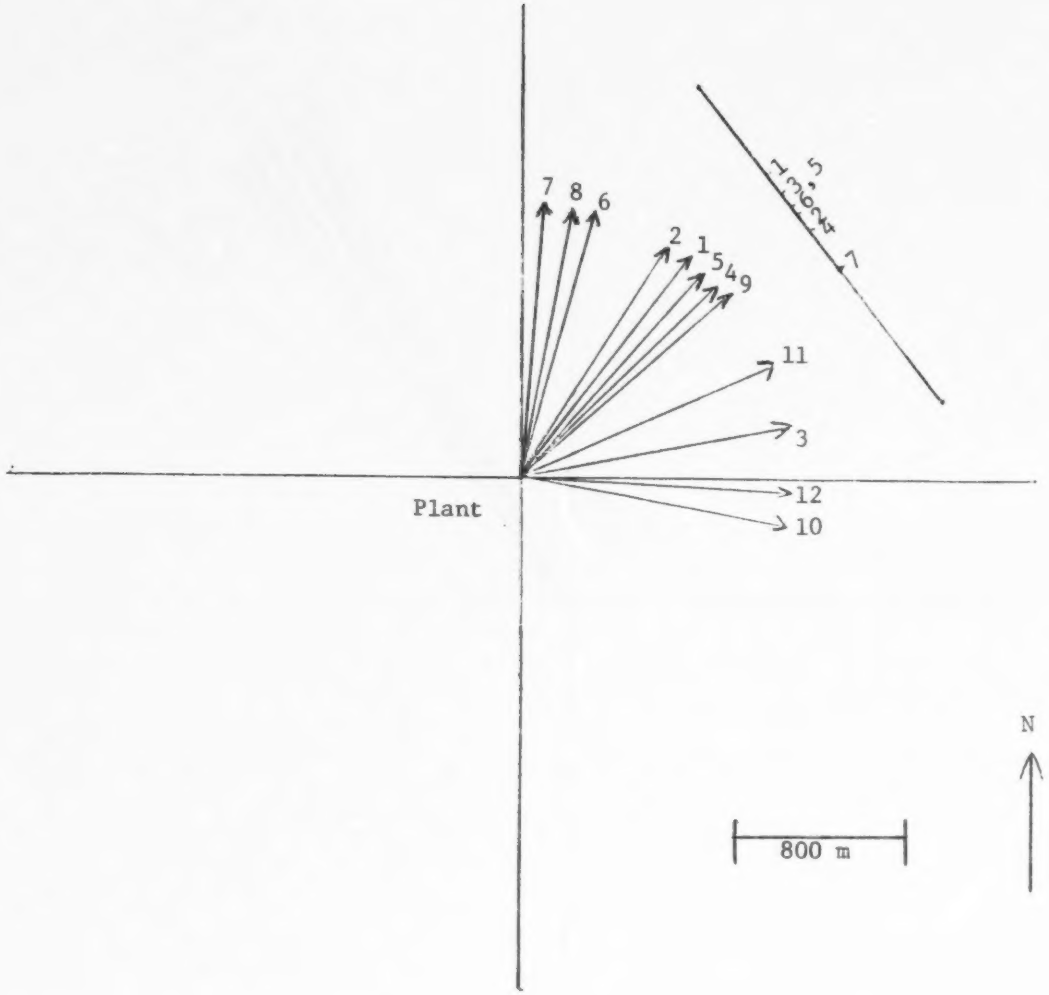
7
8
6
2
1
5
4
9
11
3
12
10
Plant
1
3,5
6
2
4
7
N
800 m

Figure 17. Two-minute Hockey 30 m wind directions and locations of peak SO_2 concentrations during cross section #4. Numbers indicate the chronological order of the wind directions and the traverses.

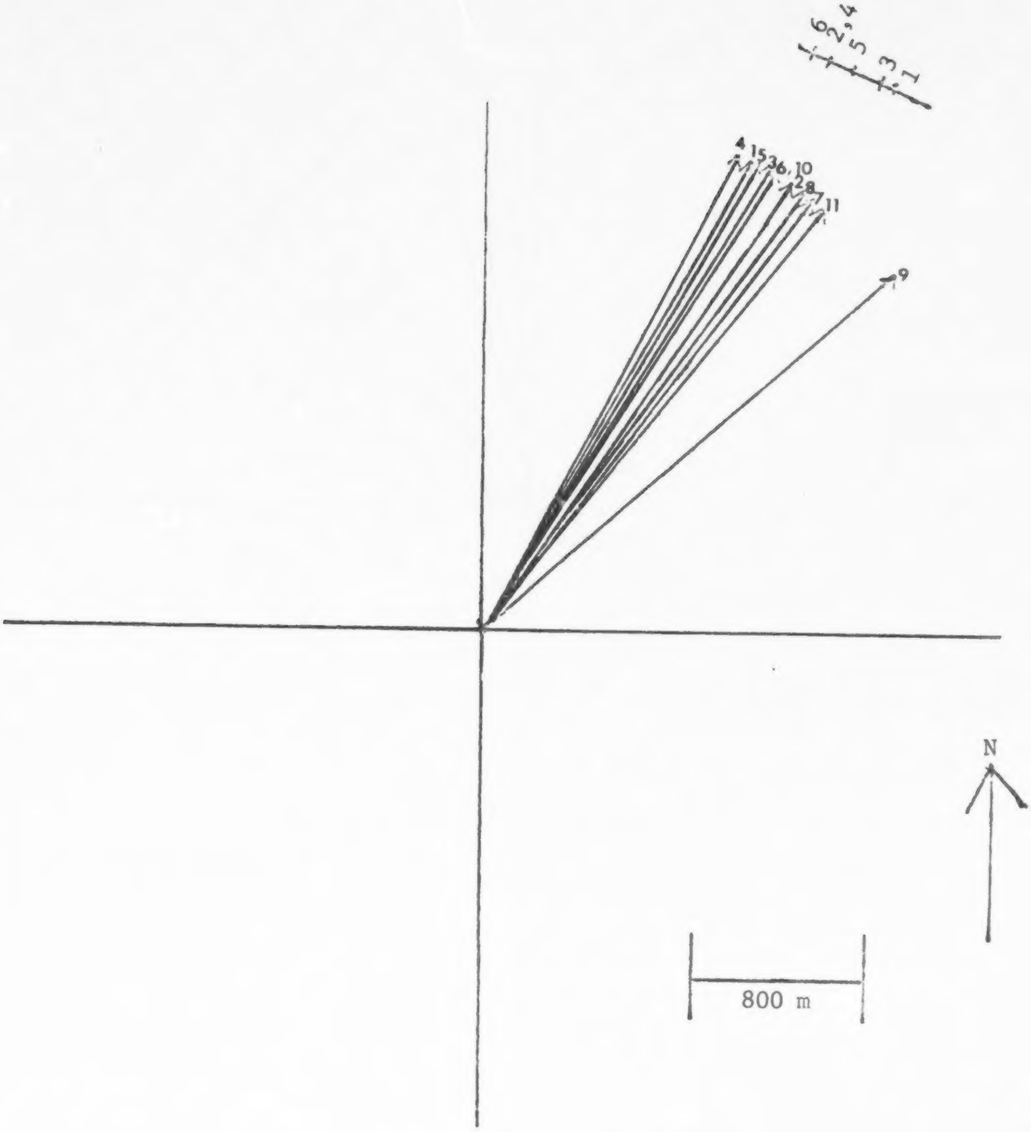
6
2,4
5
3
1
4
1
5
3
6, 10
2
8
7
11
9
N
800 m

Figure 18. Two-minute Hockey 30 m wind directions and locations of peak SO_2 concentrations during cross section #6. Numbers indicate the chronological order of the wind directions and the traverses.

successive two-minute sections of the plume. The latest vector represents the latest section of the plume to leave the stack. Printouts were obtained depicting the positions of these successive vectors using alphabetic characters. The procedure is described more fully in Section 7. Figures 19 and 20 show plume configurations at times 2 minutes apart during Cross Section #15. A 650 m shift in the plume along the traverse path occurred during this interval, based on the Hockey winds. Cross Section #15 was composed of 18 traverses along the same traverse path. The mean shift of the calculated plume configuration between traverses over the entire cross section was 290 m, while the mean shift of the peak SO_2 concentration from traverse to traverse was 321 m. The individual shifts in plume configuration ranged from 40 m to 1080 m, while the shifts in peak concentration ranged from 15 m to 850 m. However, no correlation was found between the individual shifts determined from the helicopter data and those determined from the calculated plume configurations, indicating that although the turbulence intensity in the vicinity of the plume was similar in magnitude to that at Hockey, the particular wind direction shifts occurred at different times.

The usefulness of the helicopter data can be assessed also by comparing the total mass flux of SO_2 in the plume across the plane of the cross section with the plant emission rate. The mass flux was computed by integrating the concentration data across each individual traverse to obtain a cross wind integrated concentration (CWIC). Each CWIC was then multiplied by a height interval extending from halfway between the traverse elevation and the next lower traverse to halfway between the traverse elevation and the next higher traverse. The result was a value of the mass of SO_2 contained in each horizontal strip of the plume per unit meter in the downwind direction. The mass for each traverse was then multiplied by a wind speed appropriate for each altitude, obtained from the pibal release closest in time to the cross section (sometimes as much as two hours different). Table 29 presents the computed mass flux for each cross section along with the SO_2 emission rates for the corresponding hours.

The majority of the mass fluxes are considerably less than the corresponding emission rates. The major reason for this result is the lack of sampling by the helicopter of the entire vertical extent of the plume in many cases. Cross sections numbers 9, 10, 11, 18, 25 and 26 show reasonably good comparison between the computed fluxes and the emission rates; these cross sections were each composed of a large number of traverses, allowing sampling of the entire plume. Reasonable estimates of the vertical plume dimension can only be made for these particular cross sections. The mass flux computation is also subject to error through the use of wind speed data not observed at either the same time or at the same location as the plume cross section.

PLUME POSITION

The helicopter data provide an excellent means of determining the actual location of the plume for the purposes of comparison with the location predicted by the use of observed wind data. The helicopter measurements are not useful, however, for the purpose of obtaining an accurate representation

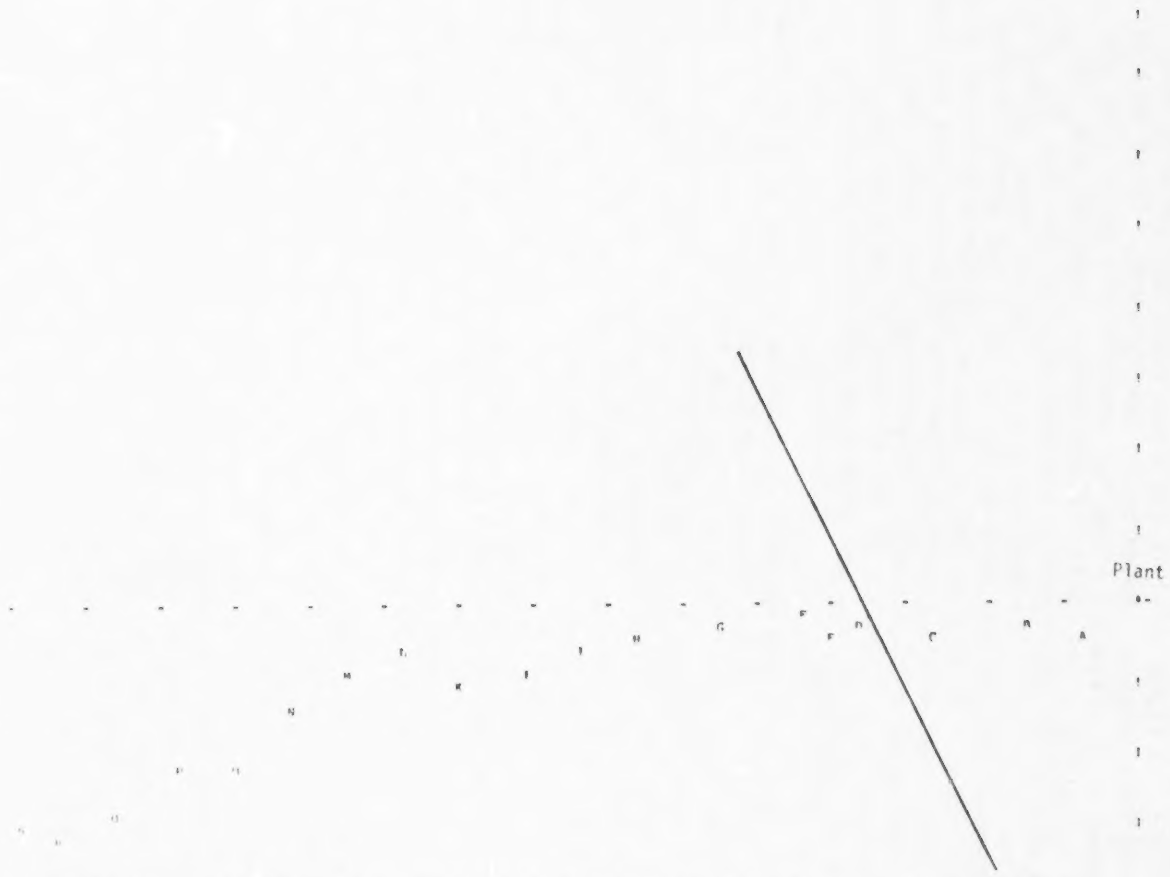

Figure 19. Plume configuration at 15:36 EST July 26, 1977 with helicopter traverse path. Point A represents endpoint of the 15:36 vector; Point S represents endpoint of the 15:00 vector. Tic marks on axes represent 0.5 km increments of distance from the plant.

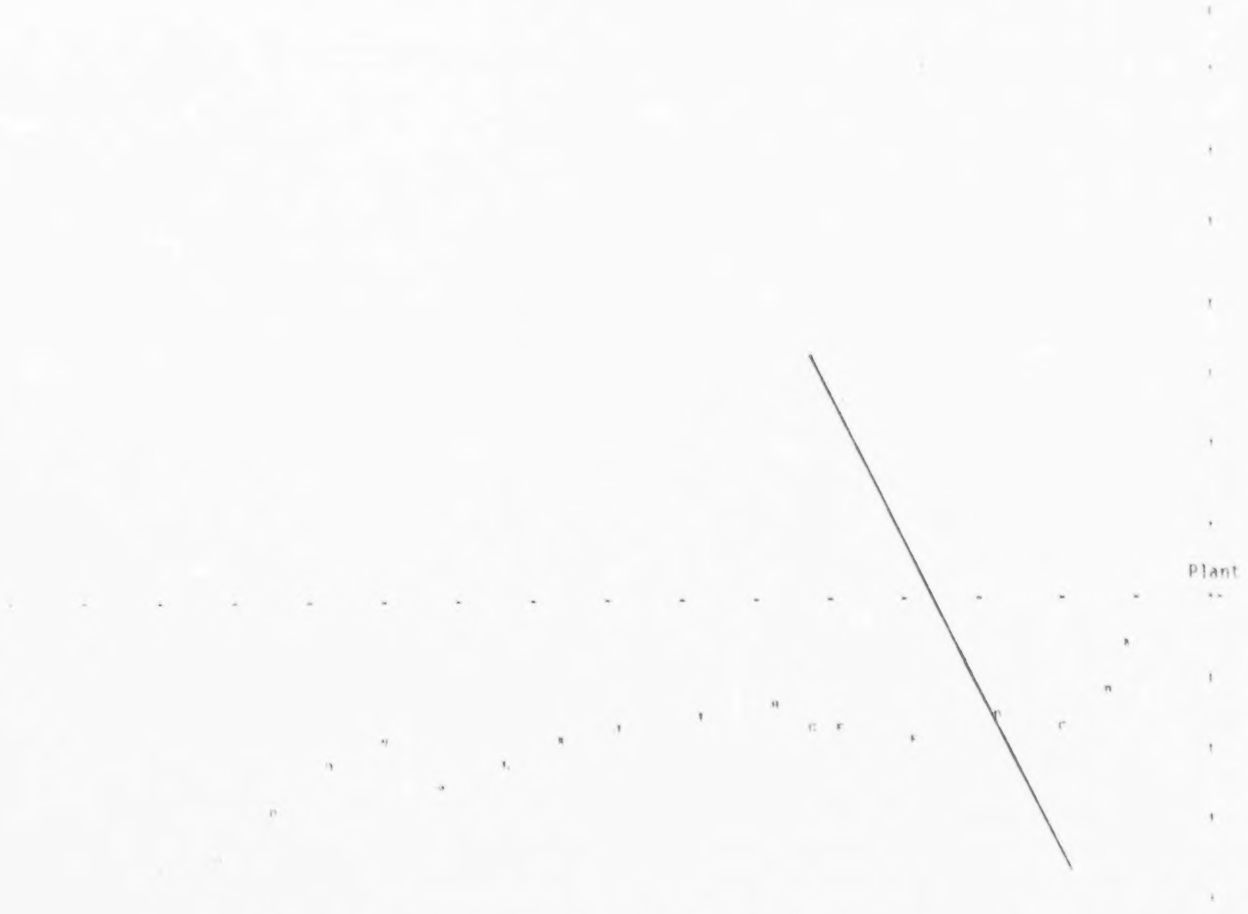

Figure 20. Plume configuration at 15:40 EST July 26, 1977 with helicopter traverse path. Point A represents endpoint of the 15:40 vector; Point T represents endpoint of 15:02 vector. Tic marks on the axes represent 0.5 km increments of distance from the plant.

TABLE 29. COMPARISON OF COMPUTED SO_2 MASS FLUX AND PLANT SO_2 EMISSION RATES

Cross section number	Number of Traverses	Total SO_2 mass flux (g/sec)	Plant SO_2 emission rate (g/sec)
1	3	131	660
2	4	118	652
3	3	71	652
4	8	125	777
5	15	190	777
6	6	180	583
7	8	191	587
8	3	148	638
9	17	777	883
10	15	1141	808
11	21	1082	934
12	5	414	928
13	13	*	1343
15	18	429	1268
17	6	311	1242
18	29	1295	1333
20	6	105	1143
22	10	131	1110
23	8	33	1076
24	16	239	1154
25	11	845	1158
26	25	1272	1394
28	12	285	1250
29	16	150	1171

* Incomplete cross section due to instrument malfunction at high altitud

of the structure of the entire plume at a particular instant in time. Plume dimensions averaged over the period of the cross section (10 minutes to 2 hours) can be derived; these computations are discussed in the subsection entitled "Plume Dimensions."

Table 30 presents the locations of the center of mass of the plume (computed from the SO_2 data) in both the horizontal and vertical. Distances from the plant were computed perpendicular to the paths of the traverses. There is considerable difference between the direction in which the center of mass of the plume was found by the helicopter and the direction in which an hourly average transport vector, based on the Hockey 30 m winds, would have carried the plume. These differences may be attributed to either terrain effects on the airflow in the vicinity of the plume or to differences in the general flow over the region between Hockey and the location of the plume.

Cross sections #1 through #5 all show substantial deviation between the location of the plume center of mass and the predicted location based on the Hockey 30 m wind data. Cross sections #1 through #3 were performed between 0956 and 1048 EST on July 23, 1977, when winds in the valley may still have been showing the effects of early morning inversion conditions with associated valley-flow regime. A pibal released at 1030 EST showed winds at approximately 500 m above plant base to be blowing toward a bearing of 8° which compares well with the plume being found at azimuths ranging from 7° to 19°. Cross sections #4 and #5 which were performed from 1403 to 1510 EST show less deviation from the Hockey 30 m flow than was evident earlier in the day.

Cross sections #11 and #12 indicated the plume center of mass to be at 54°, while the Hockey 30 m transport vector indicated the plume would have been at 74° and 93° between 1436 and 1621 EST. Pibal data from 1527 EST on July 24, 1977 show winds at plume height to be 252° to 254°, transporting the plume toward bearings of 72° to 74° respectively in agreement with the Hockey 30 m winds. It is hypothesized that in these cases the ridge immediately to the east of the plant diverted the plume to the northeast, causing it to be found at 54°, which is along the northeast slope of this ridge that parallels Sinkhole Valley (see Figure 2).

On July 27, cross section #18 was performed over a period of approximately 2 hours between 0910 and 1109 EST. Winds were shifting in a clockwise direction during this time, as three separate traverse paths were used to complete the cross section. For this reason, it is difficult to make any comparison between the hourly average Hockey winds and the plume center of mass. Cross section #20, performed in the afternoon of the same day, showed substantial deviation between actual and predicted plume location (325° vs. 277°). Pibal winds at plume height from a release at 1355 EST were blowing toward 270° in approximate agreement with the Hockey winds. The ridge immediately to the west of the plant probably diverted the plume to the northwest where lower terrain elevations are located. Later

TABLE 30. LOCATION OF CENTER OF MASS OF PLUME

Cross section number	Distance of cross section from plant (km)	Direction towards which the Hockey 30 m transport wind (degrees) would transport the plume	Bearing of x-section center of mass from power plant	Altitude of center of mass (m) MSL
1	3.0	148	7	974
2	3.0	148	14	804
3	3.0	148	19	795
4	1.8	100	49	773
5	1.8	100	55	931
6	3.1	33	34	823
7	6.2	42	35	902
8	18.2	52	54	790
9	1.8	50	54	895
10	1.8	66	57	855
11	8.2	74	54	1055
12	1.8	93	54	845
13	2.3	184	221	--
15	1.6	165	175	995
17	5.7	176	179	1018
18	1.7	296-315	333	1212
20	3.6	277*	325	1448
22	2.5	253*	267	987
23	7.6	253*	272	1146
24	7.6	242*	270	1193
25	2.5	198*	257	1044
26	1.8	26	13	1266
28	5.6	6*	28	1096
29	3.0	46	19	1188

* Based on Hockey 10 m winds.

in the afternoon a transport vector based on pibal winds at plume height (approximately 700 m above plant base) agreed with the direction of plume travel in cross section #24 (approximately 270°), while the Hockey winds indicated transport toward 240°. The pibal at 1758 EST indicated transport toward 275° at plume height, agreeing much closer to the location of the center of mass (257°) during cross section #25 than the Hockey wind.

On July 28, the location of the center of mass in cross section #29 deviated by 27° from the Hockey 30 m transport vector. Pibal data from 1300 EST indicated transport of the plume toward 26° to 38°, directions between the actual plume location and the Hockey transport direction.

The plume may have been almost immediately diverted by ridges close to the plant in several cases. Following the initial diversion, the plume traveled along Sinkhole Valley during cross sections #4, 5, 10, 11 and 12, indicating some evidence of channelization of the flow in which the plume was being transported. The lowest traverse (792 m) of cross section #7 was flown at tree-top level over Buffalo Mountain. A peak concentration of 127 ppb was found during this traverse; therefore, substantial plume impact was likely at ground level on the ridge top.

Cross sections #6 through #8 provide a series of plume traverses flown at three downwind distances from the plant ranging from 3.1 km to 18.2 km. Cross sections #6 and #7 were found at 34° and 35°, respectively, which initially places the plume within the valley through which Dumps Creek flows down to the Clinch River. Subsequently, the plume passed over Buffalo Mountain. Cross section #8 shows the center of mass to be located at a bearing of 54° at 18.2 km; the shift to the right may have been caused by the plume being diverted around Big A Mountain.

Table 31 presents an analysis of the heights of the plume center of mass as computed from the helicopter data. The plume heights above sea level, above plant base, above stack top, above the highest terrain along the traverse, and above the terrain at the center of mass are shown. Cross sections #7 and #8 had the lowest plume heights above the terrain at the plume center of mass (170 m and 58 m, respectively). Therefore, even though there was substantial impact of the plume on Buffalo Mountain in cross section #7, the plume centerline remained 170 m above the terrain. Between the locations where cross sections #6 and #7 were performed, 3.1 and 6.2 km downwind of the plant, the terrain rose 213 m. Table 31 indicates that the plume centerline was 244 m above the highest point along the traverse in #6, while in #7 the plume centerline was only 109 m above the highest terrain. This indicates that the plume height above the terrain was reduced by 63 percent of the terrain elevation difference as the plume passed over Buffalo Mountain. This parameter, the change in plume height in relation to the elevation change as a plume approaches a ridge, is important for use in dispersion models. In another case in which the plume approached Buffalo Mountain (Cross Sections #26 and #28) the plume height was reduced by 52 percent of the terrain elevation change. Cross Sections #15 and #17 can be used to analyze the approach of the plume toward Copper Ridge south of the plant. A plume height reduction of 71 percent of the terrain change was noted in this case.

TABLE 31. MEASURED PLUME HEIGHTS

Cross Section #	MSL Altitude of Center of Mass (m)	Plume Height Above Plant Base (m)	Plume Height Above Stack Top (m)	Plume Height Above Highest Terrain Along Traverse (m)	Plume Height Above Terrain at Center of Mass (m)
1	974	511	373	242	352
2	804	341	203	133	255
3	795	332	194	124	246
4	773	310	172	175	249
5	931	468	330	333	382
6	823	360	222	244	335
7	902	439	301	109	170
8	790	327	189	58	58
9	895	432	294	297	346
10	855	392	254	257	306
11	1055	592	454	457	506
12	845	382	244	247	296
13	*	*	*	*	*
15	995	532	394	324	385
17	1018	555	417	237	250
18	1212	749	611	553	724
20	1448	985	847	716	728
22	987	524	386	310	377
23	1146	683	545	469	585
24	1193	730	592	516	656
25	1044	581	443	367	495
26	1266	803	665	717	784
28	1096	633	495	303	425
29	1188	725	587	517	639

* Insufficient data due to instrument malfunction

Turner stability classes were determined from cloud information recorded by field team members and Hockey 10 m wind speed data (Turner, 1964) for each of the above three cases of plumes approaching ridges:

Cross Section #	Turner Stability Class
6, 7	C
15, 17	B
26, 28	B

The Turner Class C for cross section #6 and #7 may not be appropriate, since the plume dimensions (to be discussed in the subsection on "Plume Dimensions," which follows) appeared to more closely resemble those of stable plumes. The results of the analyses of the plume height change most closely match the plume height adjustments made in the ERT-LAPPES dispersion model (Slowik et al., 1977) which reduces the plume height above elevated terrain for all stability conditions.

PLUME DIMENSIONS

The method described by Whaley (1974) was used to compute the Gaussian dispersion parameters σ_y and σ_z from the helicopter cross-section data. First, the coordinates $(\overline{y}, \overline{z})$ of the center of mass of the plume are computed for the crosswind and vertical directions in the following manner:

$$\overline{y} = \frac{\sum_j \sum_i C_{ij} \, Y_{ij}}{\sum_j \sum_i C_{ij}}$$

$$\overline{z} = \frac{\sum_j \sum_i C_{ij} \, Z_j}{\sum_j \sum_i C_{ij}}$$

where C_{ij} is the SO_2 concentration at the i^{th} point along traverse j, Y_{ij} is the distance of the i^{th} point from a reference endpoint of the j^{th} traverse, and Z_j is the elevation above sea level of the j^{th} traverse. After these coordinates have been determined, the following equations are used to compute σ_y and σ_z:

$$\sigma_y = \sqrt{\frac{\sum_j \sum_i C_{ij} \, (y_{ij} - \overline{y})^2}{\sum_j \sum_i C_{ij}}}$$

$$\sigma_z = \sqrt{\frac{\sum_j \sum_i C_{ij} \, (z_j - \overline{z})^2}{\sum_j \sum_i C_{ij}}}$$

Horizontal dispersion parameters were computed for all cross sections while σ_z values were computed for only those cases where good comparison was obtained between the total SO_2 mass flux observed by the helicopter and the SO_2 emission rate, indicating that the full vertical extent of the plume was sampled. Table 32 presents the computed σ_y and σ_z values along with a comparison with Pasquill-Turner values (Turner, 1970) and σ_y values computed by the method of Pasquill (1976) as described by Irwin (1979). Pasquill's recommendations for predicting σ_y use measured standard deviation of wind direction fluctuations (σ_A) data (in radians) as follows:

$$\sigma_y = \sigma_A x f(x)$$

where x is the downwind distance in meters and f(x) is defined as $[(1 + 0.0308\ x^{0.4548})]^{-1}$ for $x \leq 10$ km and as $0.333\ (10{,}000/x)^{1/2}$ for $x > 10$ km.

Cloud data from field observers' notes, along with wind speeds from the Hockey 10 m level were used to determine Turner stability classes appropriate for each cross section. When σ_A is used in Pasquill's methodology, 11 cases showed Pasquill σ_y values less than the measured σ_y, while 7 cases showed the Pasquill prediction to be greater than the measured σ_y. Measurements of σ_A were not available for 6 cross sections. Over the 18 cases, the ratio (measured σ_y/Pasquill σ_y) had a mean value of 1.16, indicating favorable comparison between the measured plume spread in complex terrain and Pasquill's σ_y for the mostly unstable conditions found in this set of data. When the Pasquill-Turner σ_y values are compared with the measured values, in 18 cases the Pasquill-Turner underpredicted the measured, while in 6 cases it was an overprediction. The mean of the ratio (measured σ_y/ Pasquill-Turner σ_y) over 24 cases was 1.47. Thus, an enhancement over the standard flat terrain σ_y values is indicated.

Table 33 shows the Turner stability classes corresponding to the measured σ_y's. Twelve cases of measured σ_y greater than that for the Pasquill-Turner "A" category were noted. The most notable cases of the measured plume indicating a more stable class were #6 and #23. Over the 24 cases, the class corresponding to the measured σ_y averaged approximately half a stability class more unstable than the actual class.

Graphs of the measured σ_y values versus downwind distance were drawn for several sets of cases. Figure 21 shows the σ_y values for cross sections # 1 through #5, which were all stability class A, along with the Pasquill-Gifford curve for class A and the Brookhaven (ASME) curve (Smith, 1968) for very unstable conditions. The curves are all approximately parallel, with the curve for measured values indicating higher σ_y values than the others. Figure 22 shows similar types of curves for cross sections #6 through #8. The curve for the C stability cases shows a steeper slope than the standard curves. Figures 23 through 26 show similar curves for cases #15, #17, cases #20, #22,

TABLE 32. PLUME DIMENSIONS

Cross Section Number	Begin Event	End Event	Distance from Plant (X) (km)	Highest Altitude MSL (m)	Lowest Altitude MSL (m)	Plume Cross Section (m)		Hockey 30 m σ_A (degrees)	Pasquill $\sigma y = \sigma_A \times f(X)$ (m)	Turner Stability Class	Pasquill-Turner (m)	
						σ_y	σ_z				σ_y	σ_z
1	408	412	3.0	1006	945	528	--	63.2	1341	A	560	4700
2	416	422	3.0	854	762	869	--	23.4	482	A	550	4400
3	424	428	3.0	823	762	865	--	23.4	482	A	550	4400
4	431	445	1.8	884	671	447	--	67.3	936	A	350	1500
5	447	475	1.8	1128	701	479	--	67.3	936	A	350	1500
6	501	511	3.1	914	762	156	--	6.3	136	C	295	175
7	519	533	6.2	1006	793	756	--	10.0	410	C	550	325
8	539	543	18.2	854	732	1545	--	13.5	1049	C	1350	880
9	545	578	1.8	1220	701	414	179	17.6	243	C	177	103
10	580	608	1.8	1158	671	416	131	14.4	339	B-C	220	145
11	610	650	8.2	1311	701	932	194	18.0	912	D	465	120
12	654	662	1.8	914	671	310	67	27.9	388	C	180	105
13	701	725	2.3	1067	701	837	--	20.9	334	A	440	2550
15	749	785	1.6	1219	762	411	--	34.0	457	B	245	190
17	793	803	5.7	1098	793	507	--	10.6	401	B	740	740
18	805	861	1.7	1585	732	891	212	15.0/62.7	211/851	B/A	285/315	225/1275
20	868	878	3.6	1524	1220	477	--	--	--	A	640	5000
22	880	898	2.5	1219	732	449	--	--	--	A	470	3100
23	900	914	7.6	1219	793	134	--	--	--	C	650	390
24	916	946	7.6	1341	793	1182	--	--	--	C	650	390
25	948	968	2.5	1341	732	350	124	--	--	C	240	140
26	970	019	1.8	1463	732	682	117	--	--	C	270	210
28	023	045	5.6	1494	823	799	--	45.8	1710	B	740	740
29	047	077	2.95	1494	793	686	--	55.0	1133	B	415	360

TABLE 33. TURNER STABILITY CLASS CORRESPONDING TO MEASURED σ_Y VALUES

Cross Section	Actual Turner Stability Class	Turner Stability Class Corresponding to Helicopter σ_y
1	A	A-B
2	A	<A
3	A	<A
4	A	<A
5	A	<A
6	C	D-E
7	C	B-C
8	C	B-C
9	C	<A
10	B-C	<A
11	D	B
12	C	A-B
13	A	<A
15	B	<A
17	B	C
18	A-B	<A
20	A	A
22	A	<A
23	C	>F
24	C	A
25	C	B
26	B	<A
28	B	A-B
29	B	<A

< A means more unstable than A
> F means more stable than F

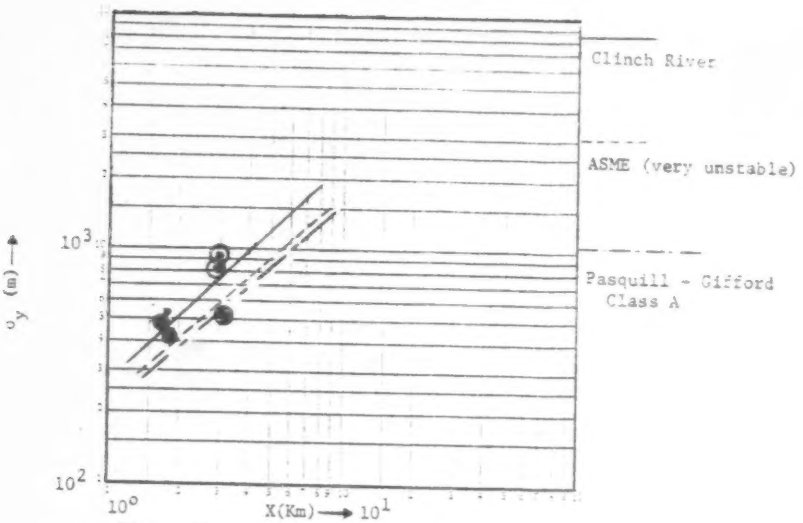

Figure 21. σ_y vs. x for cross sections #1-#5.
(July 23, 1977)

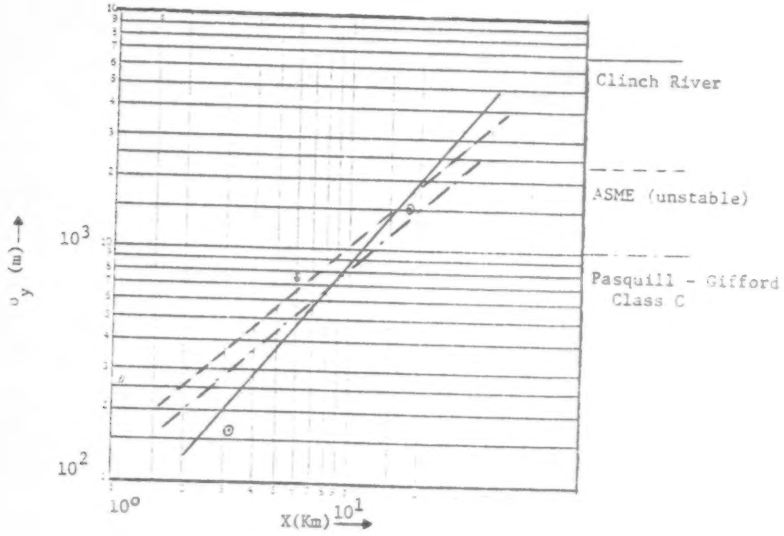

Figure 22. σ_y vs. x for cross sections #6-#8.
(July 24, 1977)

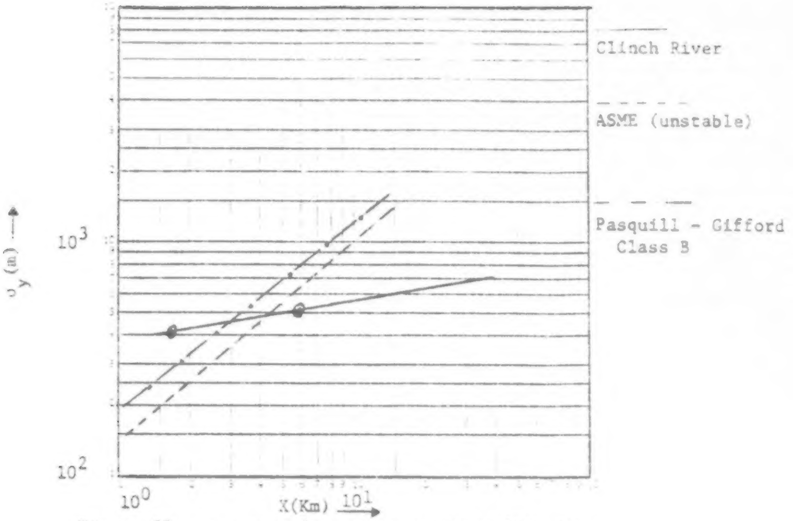

Figure 23. σ_y vs. x for cross sections #15, #17. (July 26, 1977)

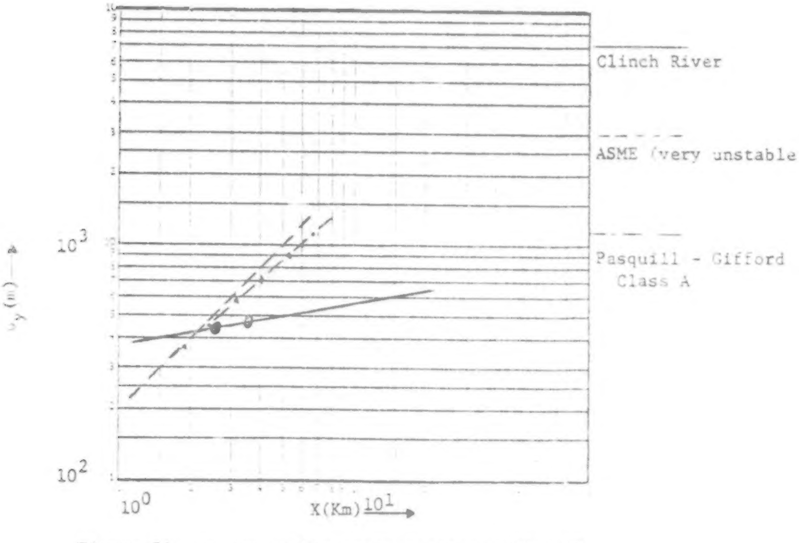

Figure 24. σ_y vs. x for cross sections #20, #22. (July 27, 1977)

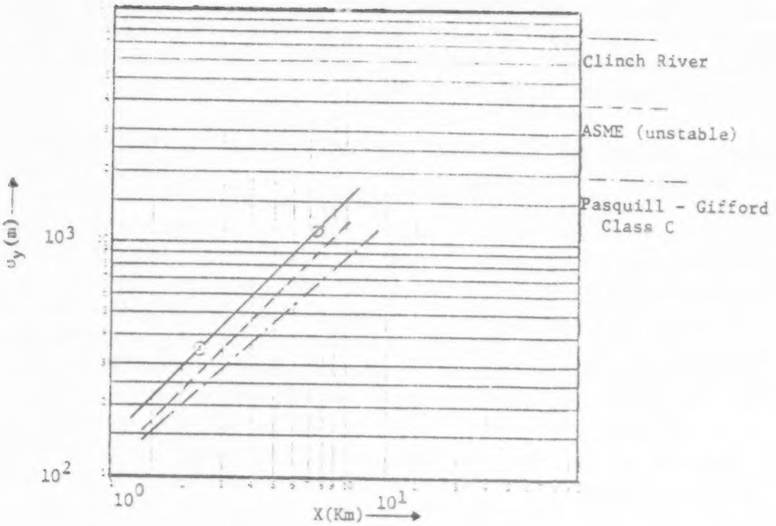

Figure 25. σ_y vs. x for cross sections #24, #25. (July 27, 1977)

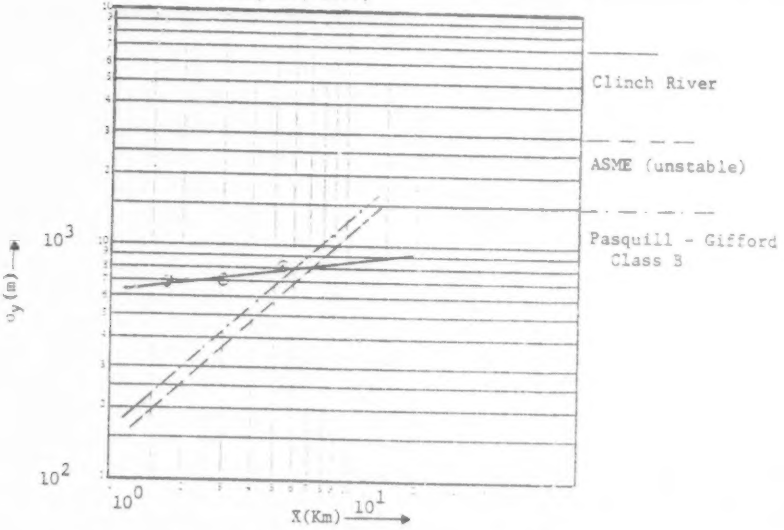

Figure 26. σ_y vs. x for cross sections #26, #28, #29. (July 28, 1977)

cases #24, #25, and cases #26, #28, and #29. Each of these groups of values form curves for classes A, B, and C with substantially different slopes than the standard curves.

For the seven cases for which σ_z was computed, the average value of the ratio (measured σ_z/Pasquill-Gifford σ_z) was 1.04, representing very little enhancement of the vertical dispersion over that for flat terrain for the mostly unstable conditions associated with these cases. However, the ratio ranged from values of 0.56 to 1.74.

Table 34 presents values of SO_2 mass per unit meter in the downwind direction for each helicopter traverse in the 24 cross sections. These values were obtained by integrating in the crosswind direction and multiplying by the height interval for which each traverse is representative. Multiple peaks can be noted in many of these vertical profiles of SO_2 mass. Well-defined double maxima occurred in cross sections #5, 9, 10, 17, 28 and 29; it is uncertain whether the double maxima result from the separate plumes being emitted from the two stacks and having undergone substantially different amounts of plume rise, or whether the phenomenon results from reflection from the surface or from a stable layer. The vertical distribution of mass for cross section #7 is unique in that it is quite uniform; this is a case of the plume passing over Buffalo Mountain. Cross section #6 shows a very compact well-defined plume with a top which is much more distinct than the bottom. Relatively high values of mass were noted on the highest elevation traverse in cross sections #10, #12, #17, #20, and #25. It is uncertain whether this phenomenon indicates a distinct plume top or the possibility that the helicopter did not go high enough to sample the entire plume.

A comparison was made between the locations where the helicopter found the plume and the fixed monitoring stations that were affected by the plume during this period. In addition, the ground mobile data were examined for sampling periods corresponding to times when the helicopter was in the air. Table 35 presents the available fixed-station and mobile data. The only fixed stations impacted by the plume during the helicopter cross sections were Tower and Johnson. The highest hourly average concentration at Tower occurred during cross section #8. During cases #7 and #8, the helicopter found the center of mass to be at 35° at 6.2 km downwind and at 54° at 18.2 km, respectively. The Tower station was located at 46° at 3.36 km and approximately 200 m below the lowest helicopter traverse of cross section #7, yet it received peak SO_2 concentrations of 165-176 ppb. The mobile van was located at 4 km and at a bearing of 25° during cross section #7, recording a peak of only 28 ppb. This location was 100 m lower in elevation than Tower. Earlier, on the same day cross section #6 had the Tower site as one of its endpoints, approximately 80 m below the lowest traverse. Tower received an hourly average of 31 ppb with a peak of 85 ppb during this time period. During cross section #10 the plume center of mass was located at 57° at 1.8 km from the plant. The mobile van was located at the same bearing during this cross section but at 11.2 km distant; an hourly average of 37 ppb was recorded which was probably mostly background since the peak was only 42 ppb, indicating very little, if any, plume impact at 579 m elevation above sea level.

TABLE 34. VERTICAL DISTRIBUTION OF SO_2 MASS COMPUTED FROM HELICOPTER TRAVERSES

Elevation (m) MSL	Mass of SO_2 (g/m)
Cross Section #1	
945	9.16
975	9.47
1006	7.54
Cross Section #2	
762	12.56
793	11.92
823	17.09
853	6.85
Cross Section #3	
823	7.29
793	11.22
762	5.28
Cross Section #4	
884	6.31
853	5.44
823	5.54
793	5.18
762	5.30
731	11.08
701	8.75
671	3.48
Cross Section #5	
701	3.89
732	4.49
762	4.21
793	4.11
823	3.97
853	4.58
884	6.90
914	8.97
945	9.00
975	4.96
1006	5.35
1036	5.51
1066	8.51
1097	5.69
1127	6.45
Cross Section #6	
762	5.25
793	9.06
823	14.33
853	13.25
883	2.77
914	0.05
Cross Section #7	
793	6.61
823	5.31
853	2.80
884	5.41
914	4.75
945	6.01
975	7.37
1006	5.25
Cross Section #8	
853	7.78
793	9.08
732	8.59
Cross Section #9	
701	9.67
732	7.33
762	8.86
793	14.13
823	1.26
853	1.47
884	4.23
914	1.42
945	3.72
975	2.35
1036	7.09
1067	3.39
1097	4.73
1127	11.41
1158	6.91
1188	7.42
1219	7.79
Cross Section #10	
1158	13.08
1097	9.72
1037	8.30
975	7.70
945	6.70
914	9.59
884	7.19
853	6.79
823	14.18
793	6.98
762	8.35
732	5.35
701	13.95
671	8.81
Cross Section #11	
701	6.78
732	4.28
762	3.41
793	3.24
823	2.75
853	5.51
884	3.64
914	4.74
975	5.11
1006	5.74
1036	3.79
1066	7.40
1097	8.23
1128	7.13
1158	10.32
1188	9.58
1219	12.89
1249	11.28
1280	10.25
1311	4.75

(continued)

TABLE 34. (continued)

Elevation (m) MSL	Mass of SO_2 (g/m)
Cross Section #12	
914	38.27
853	32.82
793	21.44
732	12.53
671	2.12
Cross Section #13	
701	2.23
732	1.76
762	4.10
793	4.24
823	8.58
853	9.99
884	9.92
914	9.02
945	17.69
975	11.97
1006	23.35
1036	10.70
1067	12.06
Cross Section #15	
762	1.70
793	1.16
823	1.77
853	1.95
884	11.22
914	12.70
945	6.37
975	16.24
1006	7.73
1036	12.95
1067	11.64
1097	15.84
1127	11.00
1158	13.51
1188	5.68

Elevation (m) MSL	Mass of SO_2 (g/m)
Cross Section #17	
1097	21.67
1036	14.06
975	2.05
914	21.34
853	5.67
793	1.94
Cross Section #18	
762	3.06
732	4.18
793	11.89
823	13.13
853	12.10
884	7.02
914	11.17
945	11.01
975	7.55
1006	17.63
1036	10.56
1067	5.09
1097	4.67
1128	0.15
1158	17.08
1188	18.96
1219	44.48
1250	26.63
1280	20.54
1311	24.16
1341	22.45
1372	27.12
1402	20.69
1432	23.03
1463	26.30
1493	8.62
1524	10.64
1555	2.86
1585	2.37

Elevation (m) MSL	Mass of SO_2 (g/m)
Cross Section #20	
1524	26.76
1463	28.94
1402	14.19
1341	4.12
1280	3.92
1219	2.28
Cross Section #22	
1219	8.63
1158	3.66
1097	27.87
1036	16.15
975	12.19
914	11.55
853	19.08
793	2.71
732	2.34
823	1.47
Cross Section #23	
1036	0.07
1097	3.14
1158	13.38
1219	0.04
Cross Section #24	
793	0.10
853	0.00
914	0.00
975	0.46
1006	1.23
1036	4.94
1067	1.78
1097	6.44
1127	8.28
1158	4.84
1189	8.18
1219	1.24
1250	2.30
1280	3.95
1310	12.98
1341	4.00

(continued)

TABLE 34. (continued)

Elevation (m) MSL	Mass of SO_2 (g/m)
Cross Section #25	
1250	29.64
1189	4.60
1127	10.66
1067	28.61
1006	45.27
945	28.67
884	14.67
823	7.89
Cross Section #26	
732	2.00
762	5.50
793	3.86
823	0.00
853	13.34
884	15.02
914	24.69
945	18.05
975	17.24
1006	23.98
1036	29.15
1067	17.66
Cross Section #26 (continued)	
1097	7.87
1128	22.03
1158	3.05
1189	12.72
1219	6.25
1250	12.10
1280	7.34
1311	6.34
1341	6.40
1372	5.55
1402	14.12
1432	14.28
1463	1.93
Cross Section #28	
823	12.53
884	6.87
945	6.90
1006	9.37
1067	9.14
1127	5.12
Cross Section #28 (continued)	
1188	7.28
1250	8.35
1311	0.93
1372	3.07
1433	0.28
Cross Section #29	
1433	4.06
1372	10.03
1311	3.77
1250	0.78
1189	1.34
1128	5.99
1067	0.35
1006	8.96
975	1.85
945	0.46
914	1.01

TABLE 35. SIGNIFICANT FIXED-STATION AND GROUND MOBILE MEASUREMENTS DURING HELICOPTER CROSS SECTIONS

	Hourly Avg SO_2/Hourly Peak SO_2				Mobile 1			
Cross Section #	Tower	Johnson	Dist. From Plant (km)	Bearing From Plant (deg)	Avg/Peak SO_2 (ppb)	Begin Time	End Time	MSL Elevation (m)
1	-	-						
2	9/54	-						
3	9/54	-						
4	15/34	-						
5	15/34	-						
6	31/85	-						
7	38/175	-	4.0	25	15/28	0919	1011	488
8	73/165	-						
9	15/34	-						
10	-	-	11.2	57	37/42	1249	1359	579
11	68/286	-						
12	-	-						
13	-	45/82	5.2	224	25/71	0955	1102	555
15	-	-						
17	-	-						
18	-	-						
20	-	-						
22	-	-						
23	-	-						
24	-	-						
25	-	-						
26	-	-	2.5	340	46/77	0953	1047	482
28	-	-						
29	-	-						

On July 26, 1977, Johnson recorded significant SO_2 concentrations during cross section #13 despite being 30° offset from the center of mass as indicated by the helicopter at 2.3 km from the plant. At 5.2 km distant and only 3° offset from the center of mass bearing, the mobile van recorded an hourly average of 25 ppb and a peak of 71 ppb. In this case the van was located approximately 150 m below the lowest traverse, indicating that the plume extended to lower elevations than those flown by the helicopter.

CONCLUSIONS

The cross sections of the plume made by helicopter are useful for determining both plume position and plume dimensions and structure. All of the cross sections are representative of daytime neutral to unstable conditions. In six cross sections in which the entire plume was sampled the mass flux of SO_2 compared well with the plant SO_2 emission rate. The amount of fluctuation of the plume from traverse to traverse as observed by the helicopter during the cross sections agreed well with the variations in wind direction and computed plume configurations using the Hockey 30 m 2-minute data. Considerable deviation of the actual plume travel direction as detected by the helicopter from the transport direction indicated by the Hockey 30 m wind and the pibal winds was noted in about half of the cases. Many of these deviations could be explained by diversion of the plume by particular terrain features such as ridges near the plant. The vertical distribution of SO_2 mass in the plume was computed and such features as multiple concentration maxima in the vertical and distinct plume tops were noted.

The helicopter cross section results have implications regarding dispersion modeling techniques. The analyses of cross sections observed as the plume approached a ridge show reductions of plume height of from 52 to 71 percent of the terrain elevation change. The horizontal Gaussian plume parameter σ_y, as observed by the helicopter is well represented by Pasquill's suggestion of:

$$\sigma_y = \sigma_A \times f(x).$$

However, the standard flat terrain Pasquill-Turner dispersion curves underestimate the observations.

SECTION 7

DEVELOPMENT OF PROFILES OF WIND AND TEMPERATURE, PLUME HEIGHTS, AND PLUME TRAJECTORIES

Two important characteristics of plume behavior are its height and horizontal position. Since these were not directly measured, except during helicopter observations, procedures were developed for using the available data to make estimates of the plume height and position. An important step in making these estimates was found to be the construction of vertical profiles of wind speed and temperature for each hour.

DEVELOPMENT OF PROFILES OF WIND AND TEMPERATURE

As part of the analysis of the Clinch River data, plume rise calculations were needed on an hourly basis for the duration of the recorded data to determine the position of the plume in the vertical. Briggs' (1975) equations, as applied by Holzworth (1978), were used to determine the final plume height (above the stack) at which the plume buoyancy flux equals zero. In order to use the Briggs/Holzworth method, a temperature and wind profile must be available for every hour of Clinch River data. Since pibal/T-sonde soundings were not performed hourly, a method was developed to estimate wind and temperature profiles.

Several alternatives were available for the development of hourly soundings; four types of data were available for use: (1) regularly scheduled 12-hourly rawinsonde data from the four National Weather Service stations closest to the Clinch River Plant (Greensboro, Nashville, Huntington, and Washington, D.C.); (2) pibal/T-sonde data observed at the Clinch River plant; (3) fixed station data from the Clinch River monitoring network; and (4) data from the 30 m mast at the Tower site. Since rawinsonde observations are scheduled twice daily at 0000 GMT and 1200 GMT (1900 and 0700 EST), use of this data requires time interpolation to obtain hourly soundings. In fact, the balloons are released 45 minutes before the scheduled observation. Also, a decision had to be made concerning which rawinsonde station or stations are the best approximation of the actual conditions at Clinch River (i.e.: the radiosonde data require testing against the pibal/T-sonde data). The pibal/T-sonde data are the best set of data available for representing actual conditions at Clinch River. However, these data are limited by the relatively small number of observations; their best use is as a test against other methods of estimating the profiles. Use of the meteorological data from the fixed stations to form profiles assumes that the stations can be used to represent actual levels in the atmosphere. The advantage of this method is that the data are available continuously as hourly averages. The disadavantages are the proximity of the instruments to the ground at the fixed stations (both temperatures and winds are affected by the ground surface despite the instruments being at the 10 m level) and the fact that the highest station is only approximately 350 m above plant base. The accuracy of this method was tested by using the pibal/T-sonde data. The Tower site had temperature sensors at 0.5, 4 and 30 m and vector vanes at 10 m and 30 m. The parameters obtained from these instruments give an estimate of atmospheric stability and also can be used in conjunction with other fixed station meteorological data to obtain a profile.

A combination of fixed-station meteorological data for the lower levels (0 to 350 m above plant base) and time-interpolated radiosonde data above 350 m has the advantages of having hourly data available for the low levels where most of the diurnal variation occurs and also of having data to as high an altitude as desired.

All pibal/T-sonde data were used to test this method by interpolating the pibal/T-sonde values to fixed station elevations (above plant base) and comparing these values with the fixed station data. The average difference and standard deviation of the difference were computed for wind speed and temperature at each station (see Table 36). The differences were computed as station value minus pibal value. The higher elevation stations (Johnson, Kents, Hockey and Hockey 30 m) exhibit a larger standard deviation for wind speed difference than the lower stations (Nash's, Munsey, Lamberts, Tower, and Tower 30 m). Also, the higher elevation stations with temperature sensors (Kent's, Hockey) exhibit a larger standard deviation for temperature difference than the lower stations (Nash's, Munsey, Tower).

TABLE 36. AVERAGE DIFFERENCE AND STANDARD DEVIATION OF DIFFERENCES OF TEMPERATURE AND WIND SPEED BETWEEN FIXED STATIONS AND PIBAL/T-SONDES

		Wind speed (m/sec)		Temperature (°C)	
Station	Height above plant base (m)	Average error	Standard deviation	Average error	Standard deviation
Nash's	82	-1.4	1.5	-2.3	1.9
Munsey	140	-1.9	2.2	0.4	1.8
Lambert	143	-1.7	2.6	-	-
Tower	143	-0.5	1.5	-1.0	1.6
Tower 30 m	168	0.0	1.8	-	-
Johnson	296	-2.0	5.3	-	-
Kent's	302	-1.0	7.7	0.5	2.8
Hockey	341	-1.7	4.8	0.2	3.3
Hockey 30 m	366	-0.7	3.7	-	-

Data from the two closest rawinsonde stations (Huntington and Greensboro) were linearly interpolated in the vertical to the pibal observation levels and then linearly interpolated in time between the 0000 GMT and 1200 GMT soundings to the pibal release times. The average differences and standard deviation of the differences were determined for temperature, wind speed, and wind direction for 50 m layers from plant base to 5000 m above plant base. Table 37 summarizes the results for the first 500 m and supplies the average difference for temperature and wind speed over the first 2000 m.

TABLE 37. AVERAGE DIFFERENCE AND STANDARD DEVIATION OF DIFFERENCES OF TEMPERATURE AND WIND SPEED FOR HUNTINGTON AND GREENSBORO RAWINSONDES VS. PIBAL/T-SONDE

Elevation above plant (meters)	Huntington				Greensboro			
	*Average Difference		Standard Deviation		*Average Difference		Standard Deviation	
	WS	T	WS	T	WS	T	WS	T
0-50	-	-4.4	-	3.5	-	-3.0	-	4.7
51-100	1.0	-1.6	2.3	3.7	1.3	-1.1	2.1	3.6
101-150	1.0	-2.5	2.6	2.7	1.2	-0.5	2.1	3.4
151-200	1.4	-1.4	2.0	3.2	1.7	0.0	2.7	4.3
201-250	0.3	-1.2	8.5	3.9	0.9	-0.1	8.4	3.2
251-300	0.6	-2.0	12.7	3.1	0.4	-0.9	1.7	3.2
301-350	1.1	-0.4	6.6	3.4	1.1	1.1	6.7	3.6
351-400	0.5	-0.5	4.8	2.8	1.6	0.9	5.0	3.4
401-450	1.4	-1.3	3.5	6.0	1.7	-0.5	3.6	6.1
451-500	1.7	-0.5	3.3	2.7	1.8	0.8	3.0	3.2
(Ave.)0-2000	0.95	-0.81			0.18	0.35		

* Average Difference = Radiosonde value - pibal value.
WS = Wind Speed, m/sec.
T = Temperature, °C

Comparing Table 36 with Table 37 it is apparent that the average differences are about the same for the fixed station vs. pibal test as compared to the radiosonde vs. pibal test. In the lower 2000 m the average wind speed difference was positive for both stations but approximately five times larger at Huntington; the average temperature difference was approximately twice as large in magnitude at Huntington than at Greensboro and of opposite sign.

Within the interval from the surface to 2000 m above plant base both radiosondes had stronger winds than were recorded (0.95 m/sec greater for Huntington and 0.18 m/sec greater for Greensboro) by the pibal. Perhaps the boundary layer winds at Clinch River are decreased due to the complex terrain. Both radiosondes had an approximately equal number of layers in which their error was smaller. Huntington was on the average colder than Clinch River by 0.81°C. However, the standard deviation of the individual errors was approximately equal for both radiosonde stations for both wind speed and temperature. The radiosonde comparisons with the pibal were not as good as the fixed-station - pibal comparisons in the layer from stack top up to 350 m above plant base.

The time interpolated (linear) Huntington and Greensboro radiosonde data were plotted and compared to the pibal/T-sonde data for selected times exhibiting varying synoptic conditions. After examining the plots, it appeared that the radiosonde temperatures were accurate above 300 m, but the linear time interpolation did not suit the lower 300 m; the morning ground-based inversions on the interpolated radiosonde data burned off too slowly and their effects were shown throughout the day (i.e., during ocurrences of afternoon superadiabatic lapse rates near the surface recorded by the pibal/T-sondes, stable layers were interpolated using the radiosonde data). For most layers, especially at Huntington, the interpolated radiosonde wind speeds were greater than the pibal/T-sonde wind speeds. On occasion, the interpolated Huntington and Greensboro radiosonde wind speeds exhibited large differences with the pibal wind speeds, especially after frontal passages or during periods of cyclonic flow.

After reviewing the test results of the fixed station vs. pibal/T-sonde and interpolated radiosonde vs. pibal/T-sonde, a methodology was developed to incorporate both radiosonde and fixed-station data for determining hourly profiles. The methodology consisted of using the hourly average wind speed and temperature values of the fixed stations from stack top to approximately 200 m above stack height. Above this layer either the Huntington or Greensboro radiosonde data or a weighted average of the two were used, depending on which of the three gives a value at the Hockey elevation which is closest to the Hockey observations. The weighted average for temperature used the average difference for the lower 2000 m calculated in the interpolated radiosonde vs. pibal analysis (all temperatures in Celsius):

$$T = \frac{T_H + (\frac{81}{35})\, T_G}{1 + 81/35}$$

where T = weighted average temperature

T_H = temperature from Huntington sounding

T_G = temperature from Greensboro sounding

81/35 = ratio of average differences for the lower 2000 m.

The weighted average for wind speed used an inverse square distance weighting relationship minus a term which was the inverse square distance weighting of the average difference for the lower 2000 m, calculated in the time-interpolated radiosonde vs. pibal analysis (all speeds in m/sec):

$$WS = \frac{(1/D_H^2)\ WS_H + (1/D_G^2)\ WS_G}{1/D_H^2 + 1/D_G^2} - \frac{(1/D_H^2)\ 0.95 + (1/D_G^2)\ 0.18}{1/D_H^2 + 1/D_G^2}$$

$$= \frac{(1/D_H^2)\ WS_H + (1/D_G^2)\ WS_G}{1/D_H^2 + 1/D_G^2} - 0.67$$

where WS = weighted average wind speed

WS_H = wind speed from Huntington sounding

WS_G = wind speed from Greensboro sounding

D_H = Huntington to Clinch River distance

D_G = Greensboro to Clinch River distance

0.95 and 0.18 = average differences between radiosonde and pibal wind speed for the lower 2000 m for Huntington and Greensboro, respectively.

Specifically, the average of the hourly temperature at Tower and Munsey and the hourly wind speed at Upper Tower were used for values at stack top; the hourly wind speed at Johnson and the hourly temperature at Kents were used for a level 150 m above the stack; and the hourly wind speed at Upper Hockey and the hourly temperature at Hockey were used for the level 200 m above the stack (see Table 1 for station elevations). A determination was made as to which time-interpretated radiosonde or weighted average radiosonde data were closest to the fixed station temperature and wind speed values at 200 m above stack top. The entire temperature or wind speed sounding (above stack top plus 200 m) of the best fitting radiosonde data was then shifted to conform to the highest fixed station values, thus providing a smooth transition between the fixed station and radiosonde data.

Figure 27 illustrates the profile methodology and a summary of the methodology follows.

Vertical Profile Methodology

1. Perform linear time interpolation of Huntington and Greensboro radiosonde data on an hourly basis.

2. Determine weighted average of the Huntington and Greensboro data.

3. Determine which of above-mentioned three soundings is closest to the Hockey value for wind speed and temperature, separately.

4. Shift wind speed or temperature values for the entire selected radiosonde sounding so that sounding value at the Hockey level equals the measured value at Hockey.

5. Merge fixed station and radiosonde data:

Elevation above stack (m)	Temperature	Wind speed
0	Average of Tower and Munsey temperature	Tower 30 m wind speed
150	Kent's temperature	Johnson wind speed
200	Hockey temperature	Hockey 30 m wind speed
Above 200	Adjusted radiosonde temperature	Adjusted radiosonde wind speed

When wind speed readings are missing below 350 m a power law is applied to obtain these values. The power law exponents are based on values obtained from wind observations at O'Neill, Nebraska, Kerang, Australia and several meteorological towers at nuclear power plant sites throughout the United States. An exponent has been derived for each of several classes of vertical temperature gradient corresponding to the six Pasquill Stability Classes (U.S. AEC, 1972). The vertical temperature gradient for the layer up to 350 m is used to determine a power law exponent for use in determining a wind speed value for the missing level. Unfortunately, no reliable power law exponents for complex terrain exist.

$$U_m = U_{350}\left(\frac{Z_m}{350}\right)^p$$

U_m is the wind speed for the missing level, U_{350} is the wind speed at 350 m, Z_m is the height of the missing level and p is the exponent chosen from Table 38.

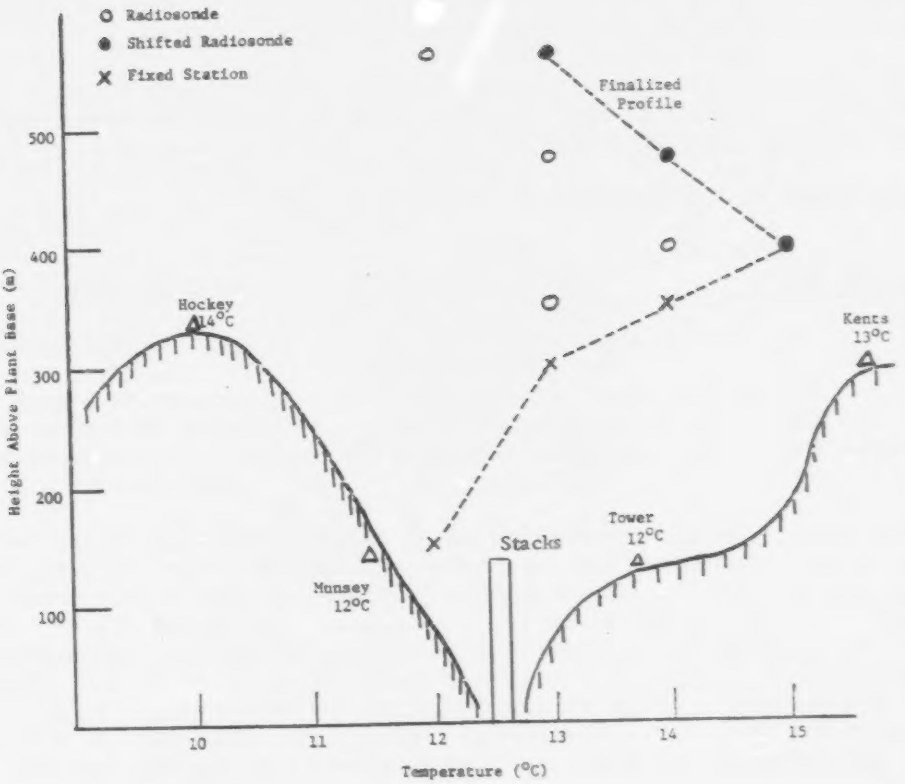

Figure 27. Example of temperature profile construction methodology.

TABLE 38. POWER LAW EXPONENTS

$\Delta T/\Delta Z$(°C/100 m)	P	
< -1.9	0.10	
-1.9 to -1.7	0.10	
-1.7 to -1.5	0.10	
-1.5 to -0.5	0.12	day
	0.21	night
-0.5 to + 1.5	0.35	
> +1.5	0.49	

Profiles of wind speed and temperature were produced on an hourly basis for the lower atmosphere at the Clinch River site using the above methodology for the period October 12, 1976 through September 30, 1977. Data collected prior to October 12, 1976 is less complete and of less interest because of uncertainties and incompleteness in the ground level concentration measurements.

PLUME HEIGHT ESTIMATES

The Environmental Protection Agency has been using the formulations of Briggs (1969, 1975) for estimating plume rise. The 1975 work presented formulas for plume rise through an atmosphere with vertically varying profiles of wind speed and temperature. Holzworth (1978) applied Briggs' method in estimating effective stack heights using standard rawinsonde observations. This same technique was applied to the hourly profiles of wind speed and temperature which had been generated for the Clinch River site.

Briggs' method of calculating plume rise through variable temperature and wind speed profiles consists of following the buoyancy flux of a plume segment through successive layers where it is either depleted or enhanced until the level is reached where the buoyancy flux is zero. The initial buoyancy at the top of the stack (F_o) is:

$$F_o = 3.7 \times 10^{-10} Q_H$$

where Q_H is the heat emission rate in cal/sec, computed from

$$Q_H = 83.45 Q_V P_o \frac{T_s - T_o}{T_s}$$

where Q_v is the volume emission rate from the stack in m^3/sec, P_0 is the atmospheric pressure at the top of the stack in mb, T_0 is the air temperature at stack top, and T_s is the stack gas exit temperature, both in °K. Hourly values of Q_v and T_s were available for each unit of the Clinch River Plant from the plant emissions file. Atmospheric pressure was also recorded at the plant, while the stack top air temperature was taken from the level of the temperature profile most closely corresponding to the level of the stack top.

Each sounding is divided into successive layers in which the change of temperature with height [$\Delta T/\Delta Z$(°C m^{-1})] and wind speed [$\Delta U/\Delta Z$(s^{-1})] both are constant and linear. The height above the stack top of the bottom of each such layer is specified as Z_{n-1} and the top as Z_n. Thus, the stack top is the bottom of the lowest layer, where $Z_{n-1} = 0$ and F_0 becomes F_{n-1}. The buoyancy flux at the top (F_n) of each successively higher layer is calculated until it becomes negative. For the layer immediately above the last level where the buoyancy flux was positive, F_n is set equal to zero and the equation is solved for the plume rise (Z_e) above the physical stack height. The effective stack height equals the physical stack height plus the plume rise.

There are two sets of equations for calculating F_n and Z_e. The first set is for no-wind conditions, e.g., nearly vertically rising plumes, where T (°C) is air temperature and Z (m) is height above the top of the stack.

$$F_n = F_{n-1} - \frac{0.265 F_0^{1/3}}{273 + 0.5\,(T_n + T_{n-1})} \left(\frac{T_n - T_{n-1}}{Z_n - Z_{n-1}} + 0.01 \right) \times \left(Z_n^{8/3} - Z_{n-1}^{8/3} \right),$$

$$Z_e = \left\{ Z_{n-1}^{8/3} + 3.77 \left(\frac{F_{n-1}}{F_0^{1/3}} \right) (273 + T_{n-1}) \times \left[\frac{Z_n - Z_{n-1}}{T_n - T_{n-1} + 0.01(Z_n - Z_{n-1})} \right] \right\}^{3/8}$$

The second set of equations is for with-wind conditions, i.e., nearly horizontally rising plumes,

$$F_n = F_{n-1} - \frac{0.523}{273 + 0.5(T_n + T_{n-1})} \left(\frac{T_n - T_{n-1}}{Z_n - Z_{n-1}} + 0.01 \right)$$

$$\times \left[0.5(U_n + U_{n-1}) \right] (Z_n^3 - Z_{n-1}^3),$$

$$Z_{e1} = \left\{ Z_{n-1}^3 + \frac{1.91F_{n-1}(273 + T_{n-1})}{U_{n-1}} \right.$$

$$\left. \times \left[\frac{Z_n - Z_{n-1}}{T_n - T_{n-1} + 0.01(Z_n - Z_{n-1})} \right] \right\}^{1/3},$$

$$Z_e = \left\{ Z_{n-1}^3 + \frac{1.91F_{n-1}}{0.5\,(U_{n-1} + U_{e1})} \left[273 + 0.5(T_{n-1} + T_{e1}) \right] \right.$$

$$\left. \times \left[\frac{Z_n - Z_{n-1}}{T_n - T_{n-1} + 0.01(Z_n - Z_{n-1})} \right] \right\}^{1/3}$$

where U is wind speed (m s^{-1}). Z_{e1} is a preliminary estimate of the plume rise above the stack top. This step is necessary because the equation for Z_e can be sensitive to the wind speed (U_{e1}) at the plume-rise height (i.e., at Z_{e1}).

Specification of sufficiently slow winds for use of the no-wind equations is somewhat arbitrary in some cases and is based on the personal recommendation of Briggs. For layers with $U = 0.0$, there is no ambiguity and the no-wind equations are used. For all other layers we interpolate to the level Z_{ub} at which the critical wind speed (U_b) occurs, i.e.,

$$U_b = \left(\frac{0.18F_0}{Z_n + Z_{n-1}} \right)^{1/3}$$

If U_b occurs in the particular layer, the no-wind equations are used in the sublayer with $U \leq U_b$ and the with-wind equations are used in the sublayer with $U \geq U_b$. If, in the particular layer, all $U > U_b$, the with-wind equations are used for the entire layer; if all $U < U_b$, the no-wind equations are used.

Since the Clinch River plant has two stacks, the method described by Briggs (1974) was applied to the estimates obtained from the above method to account for the enhancement of the plume rise due to multiple plumes. The enhancement to the plume rise from Stack #1 is computed as follows:

$$\Delta h_N = E_N \Delta h_1$$

$$E_N = [(N + S)/(1 + S)]^{1/3}$$

$$S = 6[(N - 1)d_c/N^{1/3}\,\Delta h_1]^{3/2}$$

In these equations Δh_N represents the enhanced plume rise, Δh_1 is the plume rise from Stack #1 before aplying the enhancement factor E_N. N is the number of stacks and d_c is the spacing between the stacks. The enhancement to the plume rise from Stack #2 is computed in the same manner, using Δh_2 in the above equations instead of Δh_1. An average plume rise was also computed using the average heat emission rates of the two stacks.

Plume height estimates were made for the period July 23 to July 28, 1977, using the above method based on the average heat emission rate, without the multiple stack enhancement factor. Helicopter measurements of the plume were available during this period. In addition, the Briggs subroutine BEH072 from the UNAMAP series of EPA programs was run for the same period using Turner stability classes derived from cloud and wind speed data and the same average stack heat emission rate. The center of mass in the vertical was computed for each of 23 helicopter cross sections of the plume and these heights were compared with the two sets of plume height estimates (see Table 39). The Holzworth/Briggs value is the plume height computed using the average heat

TABLE 39. COMPARISON OF PLUME HEIGHT MEASUREMENTS AND ESTIMATES

Plume Center of Mass (Helicopter Measurement) (m) MSL	Holzworth-Briggs Plume Height (m) MSL	Briggs BEH072 Plume Height (m) MSL
974	792	1,838
804	800	1,494
795	800	1,494
773	999	1,255
931	999	1,255
823	769	828
902	809	816
790	750	784
895	910	781
855	929	832
1,055	927	866
845	921	1,065
995	908	1,185
1,018	925	1,100
1,212	761	1,134
1,448	958	2,096
987	816	1,566
1,146	816	1,494
1,193	934	1,589
1,044	934	1,522
1,266	*	1,564
1,096	*	1,321
1,188	*	1,537

* Wind speed and temperature profiles not available.

emission for the two stacks. The mean absolute error for the Holzworth/Briggs method was 143 m, while for Briggs BEH072 subroutine the mean absolute error was 321 m. Subsequently, it was determined that if a plume rise enhancement factor were included, the mean absolute error for the Holzworth/Briggs method would be reduced by 15 m; however, the absolute error for the BEH072 method would be increased.

The plume heights based on separate estimates for each stack were computed for the entire set of wind speed and temperature profiles (October 12, 1976 through September 30, 1977). The statistics in Table 40 were generated in comparing the plume heights from the two stacks with the vertical temperature structure. The percent of the time that the plume was contained in an inversion layer reached a maximum at 0500 EST and a minimum by 1300-1400 EST; this reflects the diurnal cycle of stability in the boundary layer. Also, at 0500 EST the fraction of the time when the plume was below an elevated inversion was at a minimum. By 1800-1900 EST a very large percent of the cases (77 percent) showed plumes below elevated inversions. No inversion existed in the profile least often (1 percent) between 0600 and 0800 EST and most often at 1300 EST (11 percent).

DEVELOPMENT OF PLUME TRAJECTORIES

The soundings and plume height estimates aid in determining the position of the plume in the vertical. A method is also needed for estimating the plume position in the horizontal on a routine basis; therefore, the development of a method of predicting the plume trajectory was needed.

The trajectory development was initiated by reviewing the July 1977 helicopter data. Methods of estimating a plume trajectory were tested against the position of the plume as determined by the helicopter cross sections. The Hockey 30 m wind data were found to be the most reliable in estimating the plume position. Other methods such as spatial interpolation of fixed-station wind data were rejected due to an inadequate number of stations located at or near typical plume heights.

The following plume trajectory criteria were established for the vicinity of the Clinch River monitoring network which extends to a maximum of 30 km. from the plant:

For daylight hours

1. Use hourly average Hockey 30 m wind vector when wind speeds are greater than 3.0 m/sec and the standard deviation of the wind direction fluctuations (σ_A) is less than 25°.

2. Use the 2-minute raw data from the Hockey 30 m level to construct a curvilinear trajectory over the period of an hour for wind speeds between 1.0 m/sec and 3.0 m/sec and σ_A between 25° and 40°.

TABLE 40. SUMMARY OF PLUME HEIGHTS IN RELATION TO VERTICAL TEMPERATURE STRUCTURE, OCTOBER 12, 1976 - SEPTEMBER 30, 1977

Hour	% In Inversion		% Below Inversion		% Above Inversion		% No Inversion
	Stack 1	Stack 2	Stack 1	Stack 2	Stack 1	Stack 2	
1	57	55	32	39	7	2	4
2	58	56	32	38	6	2	4
3	61	57	32	39	5	2	3
4	61	59	33	39	4	0	2
5	65	60	30	38	3	1	2
6	61	57	32	39	5	2	1
7	61	59	32	39	6	0	1
8	58	57	35	40	5	1	1
9	54	53	35	43	8	1	3
10	43	41	46	51	8	4	3
11	34	32	53	58	7	4	6
12	29	30	55	58	9	4	7
13	21	22	58	61	10	5	11
14	22	20	62	66	6	5	9
15	22	25	64	64	6	4	8
16	23	25	61	63	8	4	8
17	21	20	65	69	7	3	7
18	15	15	72	74	6	4	7
19	19	19	71	75	5	2	5
20	29	29	57	62	10	5	4
21	38	39	48	53	11	5	4
22	47	46	41	45	8	4	4
23	54	53	34	40	8	4	3
24	57	54	33	39	6	3	4

3. If the wind speed is less than 1.0 m/sec or the σ_A is greater than 40° the trajectory can be categorized as either (i) indefinite or (ii) a stagnation situation.

For night

1. For cases when plume rise was low (plume did not penetrate inversion), assume stagnation conditions.

2. For cases of high plume rise (i.e., plume above inversion), use same criteria as daytime.

Indefinite plume trajectories occur when the plume is transported in myriad directions due to highly variable winds. Stagnation cases occur when the plume is trapped beneath a stable layer and there is insufficient wind to transport the plume. In this case, the plume just disperses in all directions in the layer below the inversion.

Eighteen percent of the hours in a test sample of 46 days and nights fit the criteria for curvilinear trajectories. An additional 38 percent of the hours in the 46 day test sample were determined to be indefinite or stagnation situations. The remaining 44 percent of the hours met the criterion for uniform linear flow. The development of a technique for displaying the plume position or configuration at any point in time was considered necessary in analyzing the reasons for particular stations showing impact of the effects of the terrain on the plume. To satisfy both the need for curvilinear trajectories and the need for "snapshot" representations of the plume, a computer program was developed to produce a graphical display of the plume configuration using the 2-minute wind observations from the Hockey 30 m level. The program advects each 2-minute section of the plume arleady in the atmosphere using the latest 2-minute wind vector. The latest vector also represents the latest section of the plume to leave the stack. The program can print a "snapshot" of the plume at any given 2-minute increment of time, using the latest set of 30 2-minute observations covering an hour of time. During the helicopter monitoring period in July 1977 the plume configuration was produced for every 2 minutes during several of the cross section observations. For each of the case studies (described in Section 8) one plume configuration was computed and displayed for each hour on the hour for a 48-hour period containing a case of high pollutant concentration.

Analysis of these printouts can assist in determining if the plume followed the Hockey winds or was affected by the terrain features. Figure 28 is an example of the plume configuration displays produced for the period of the helicopter cross sections. The figure shows the plume position at 1428 EST on July 23, 1977 during the helicopter cross section #4. The vector from the plant to the second point D at the end of the plume represents the section of plume emitted an hour earlier and transported by successive 2-minute vectors to its position at 1428 EST. The graphical displays of the plume configuration were produced on the line printer at the same scale as the 7.5 minute U.S. Geological

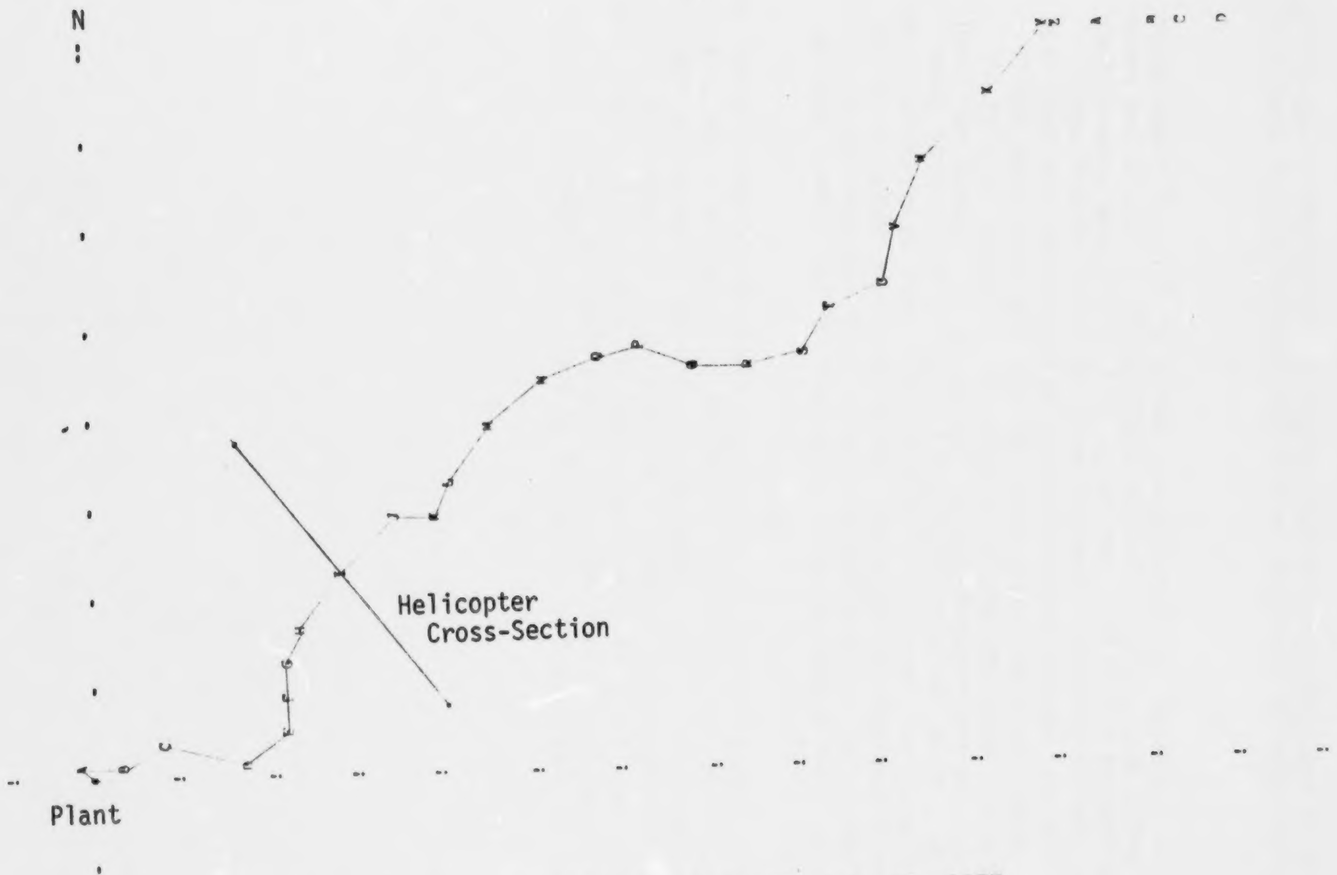
N
Helicopter
Cross-Section
Plant

Figure 28. Plume Position at 1428 EST, July 23, 1977
Computed by Trajectory Analysis for 60 Minutes

Survey maps (1 in. = 24,000 in.). An overlay was produced from the USGS maps that cover the region surrounding the Clinch River plant for use in analyzing the plume position in relation to the terrain. Tic marks on the axes of the graphical displays represent 0.5 km increments of distance from the plant.

Description of the usefulness of this graphical technique in explaining high concentration cases is contained in the Case Studies part of Section 8.

SUMMARY

A method was developed for constructing hourly profiles of temperature and wind speed using hourly ground station observations at five sites representing three different elevations, and twice daily rawinsonde observations. The constructed profile compared favorably with 350 local pibal/T-sonde observations. The root-mean-square-difference in temperature was less than 2°C up to 200 m above the plant base, about 3°C for the layer from 200 to 400 m above the plant base, and generally about 4°C (although as high as 6°C) above 400 m. The root-mean-square-difference in wind speeds was about 2 m/sec up to 200 m above the plant base and averaged about 5 m/sec above 200 m. The wind speed and temperature profiles were used to determine plume height by a method developed by Holzworth and originally proposed by Briggs. In comparing plume height calculations with helicopter measurements of 20 plume cross-sections, we found a mean absolute difference of 130 m and a mean measured plume height of 978 m.

An objective method was developed for calculating plume trajectories based on average 1-hour winds (linear 1-hour trajectory) or based on 2-minute winds (curvilinear trajectory). Linear trajectories occurred 44 percent of the time and curvilinear flow was found 18 percent of the time. The remaining 38 percent of the cases were found to consist of irregular and poorly defined flow. Most of the irregular flow situations occur during nighttime hours, i.e., about 60 percent of nighttime hours compared to about 16 percent of daytime hours.

SECTION 8

ANALYSIS OF PLUME IMPACT IN RELATION TO METEOROLOGICAL CONDITIONS

Two approaches were utilized in analyzing the plume impact within the fixed-station network. The first method was a statistical approach, which involved producing joint frequency distributions of the pollutant concentrations in association with a number of meteorological parameters. During this stage of the analysis statistics were also generated on the meteorological data itself. The second approach was a case study analysis in which eight specific high pollution incidents were studied in depth to determine the causes for the plume impacts and to gain a better understanding of the plume transport and diffusion processes that were occurring.

METEOROLOGICAL DATA

Frequency distributions of wind direction, speed, and σ_A by hour of the day for each of the eight fixed stations are presented in Appendix B.

The frequency distributions of wind directions recorded at each station show a significant influence of the terrain in the immediate vicinity. Examples can be cited to illustrate the relationship of prevailing wind directions to local terrain features shown in Figure 31. The most frequent 10° wind direction class at Johnson is 310°-320°. This class occurred most frequently from late morning through late afternoon and is upslope flow through a hollow in Copper Ridge. Lambert shows most frequent wind direction classes of 250°-260° and 260°-270°, indicating channeling of the airflow along Reed's Valley. Both the upper and lower levels at Hockey have most frequent wind directions that are upslope along a hollow on Copper Ridge. The upper level has a peak in the distribution 220°-230° class, while the lower level exhibits a maximum in the 200°-210° class. Munsey's most frequent wind direction is 120°-130° occurring mainly in the morning and evening. This flow represents drainage through a hollow in Copper Ridge. Nash's shows the highest frequencies in the adjacent 220°-230° classes which are oriented along nearby Thompson Creek. The upper and lower Tower levels have highest frequencies of wind directions in the ranges of 220°-260° and 240°-270°, respectively. These ranges are slightly more frequent from mid-morning through late afternoon than any other part of the day, suggesting some upslope flow toward the Tower site from Dumps Creek. Castlewood's most frequent wind directions are in the range 280°-310° which is up-river flow along the direction of the Clinch River Valley.

Wind roses have been generated from the Clinch River wind data by Maxwell (1979). A particularly interesting terrain influence on the air flow is demonstrated by the wind roses for Munsey. Figures 29 and 30 contain wind roses for the months July-September 1977 by individual 3-hour periods of the day. A very pronounced downslope flow (approximately 120°) develops at night at Munsey as demonstrated by the wind roses for hours 0200-0400, 0500-0700, 1700-1900, 2000-2200 and 2300-0100 EST. This phenonemon may be important in bringing the elevated power plant plume down to the elevation of Munsey.

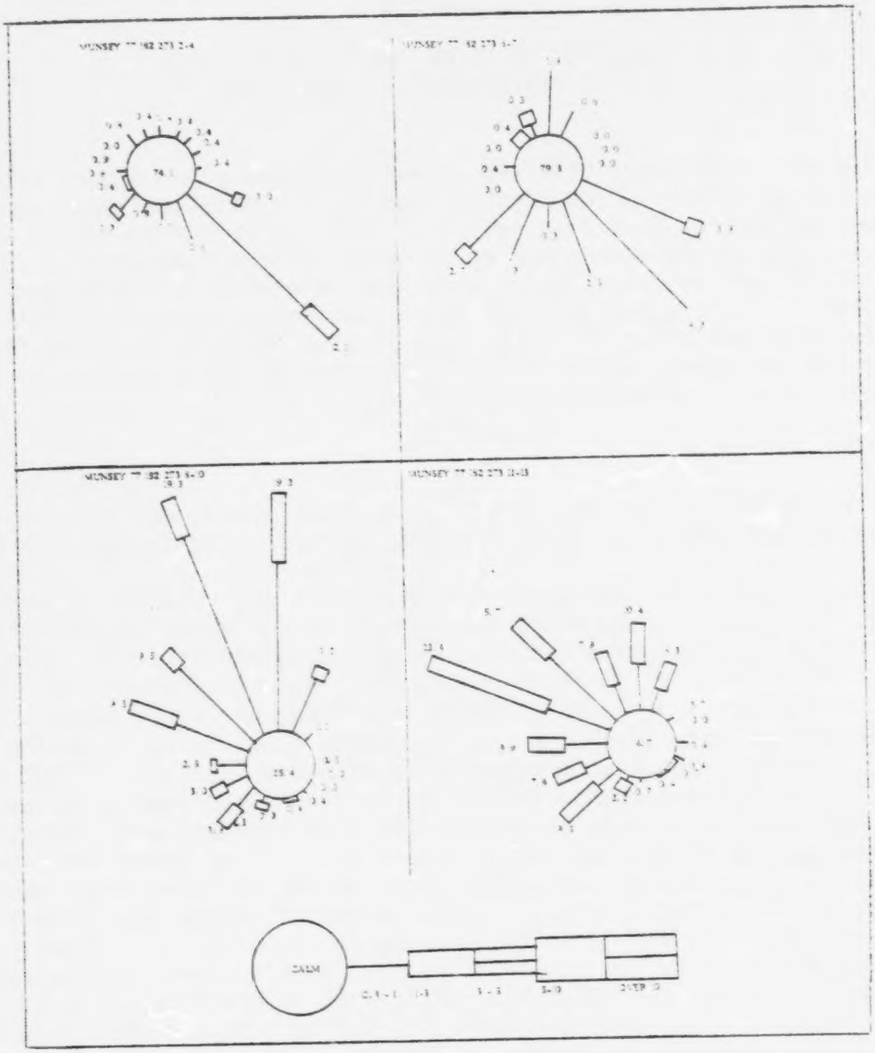

Figure 29. Munsey wind roses for July-September 1977, for 3-hourly periods during 0200-1300 EST.

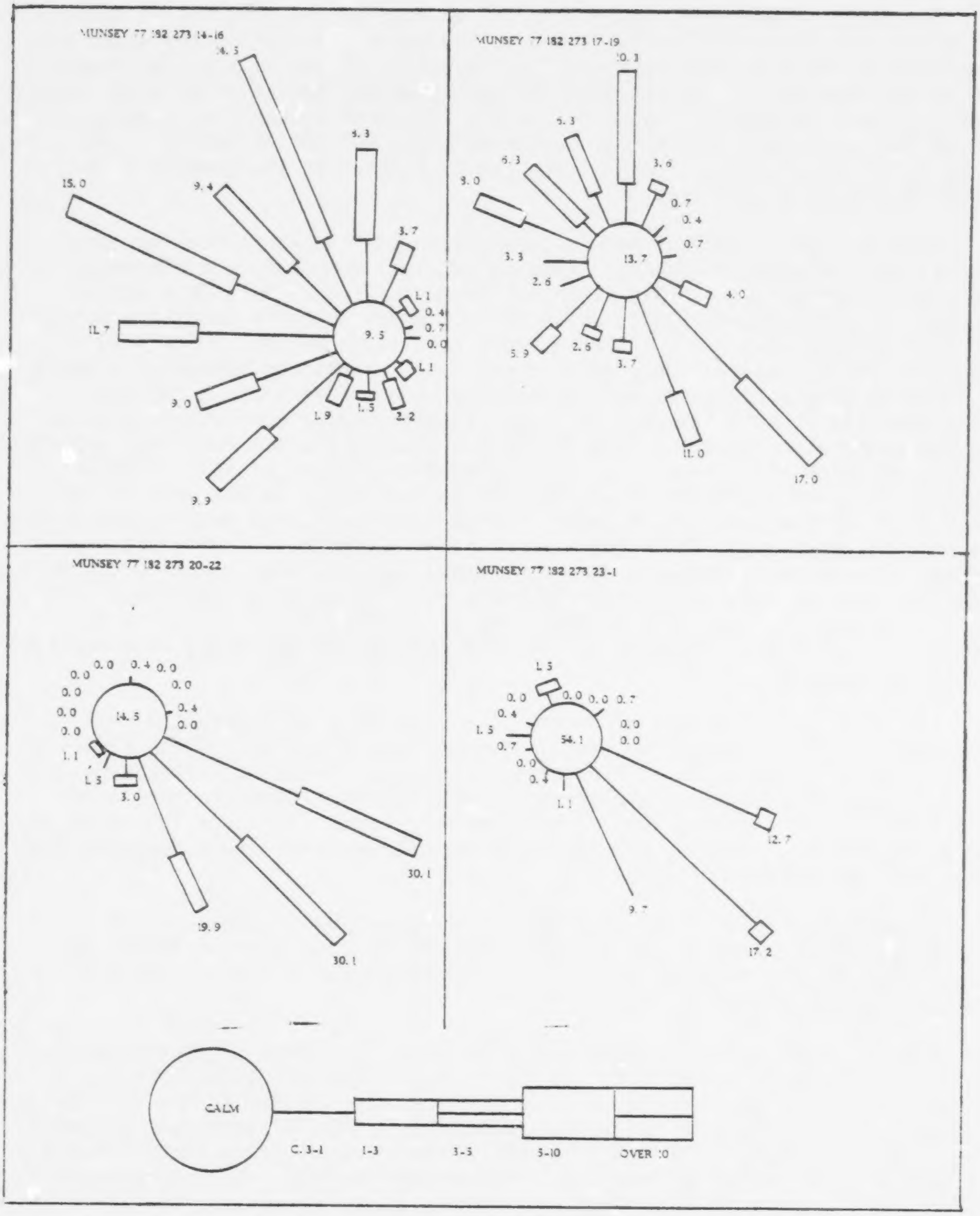

Figure 30. Munsey wind roses for July-September 1977, for 3-hourly periods during 1400-0100 EST.

The most frequent wind speed interval at most of the stations is either 0-1 m/sec or 1-2 m/sec. The exception is the upper level of Hockey which has a maximum in the 3-4 m/sec interval. All stations except Nash's, Castlewood and Munsey have 10°-20° as the most frequent standard deviation of wind direction (σ_A) over periods of 1-hour in length. The most frequent σ_A classes are 30°-40° at Nash's, 50°-60° at Castlewood, and 60°-70° at Munsey. The large σ_A values at these sites reflect the disruption to the general flow caused by the local terrain.

Frequency distributions were also analyzed for the additional meteorological data recorded at Tower, including vertical temperature differences and wind elevation angle. The strongest inversion from 0.5 to 30 m was an increase of greater than 3.3°C, while the strongest unstable condition was a decrease of more than 2.4°C. Strong lapse conditions between 0.5 and 30 m generally occur simultaneously with strong lapse conditions between 0.5 and 4 m. However only a few cases existed showing strong inversions occurring simultaneously in both layers. It was difficult to draw conclusions regarding the temperature gradient from 0.5 to 4 m because the 4 m level was apparently reading too high after the sensor was replaced in October of 1976. The most frequent standard deviation of wind elevation angle (σ_E) values were in the range 6°-9° at the lower Tower level. These values occurred most frequently in the morning and evening while the maximum range recorded (36°-39°) occurred at midday. The upper σ_E showed a similar diurnal pattern. High values of σ_E were recorded simultaneously with unstable lapse rates measured on the Tower. There was also a general trend of high σ_E values at the 10 m level occurring more frequently with low σ_A readings at the 30 m showing the influence of convection induced turbulence.

Frequency distributions of Hockey 30 m wind directions versus directions at each of the other individual stations were produced. These distributions clearly indicated the differences in the wind direction patterns between those found at the valley and plateau stations and the closer to free atmosphere flow represented by the Hockey 30 m level wind. For each 10° range of Hockey 30 m wind direction, the preferred directions occurring at each of the other stations were determined.

Hockey 30 m versus 10 m comparison shows almost a 1:1 relationship. For each Hockey 30 m category, the preferred Hockey 10 m category is 10° to 30° less. That is, the average Hockey 10 m wind direction is backing about 20° with respect to the Hockey 30 m wind.

Munsey shows a distinct preference for wind directions of approximately 130° over the entire range of Hockey 30 m winds. The 130° wind direction at Munsey corresponds to flow down a mountain hollow on a ridge to the southeast of Munsey, thus explaining the preference for this wind direction as drainage flow. Munsey is located near the bottom of a northwest facing ridge along a 1/2 to 1 km wide valley aligned approximately 60° to 240°. Wind directions of 220° -360° represent flow aligned with the valley or crossing the width of the valley before reaching Munsey which lies close to the northwest side of

Copper Ridge. For Hockey winds of 180°-210° the preferred Munsey directions are centered around 240° and 130°. These directions represent up-valley flow and drainage flow, respectively. The Munsey direction matches the Hockey direction best for the Hockey range 260°-360°. The Munsey winds are scattered for the Hockey range 210°-250°.

The Nash's site is located on a plateau with a steep upslope about 0.3 km to the SE. The plateau and ridge are aligned approximately 55° to 235°. There is a definite preference for Nash's wind directions to be aligned along the axis of the plateau and ridge. For Hockey wind directions, ranging 0° - 180° the Nash's most frequent directions occur in the 20°-70° range. This direction corresponds to the axis of the plateau. A maximum frequency also occurs for Nash's winds at 0-20° with Hockey winds at 0-20°. For Hockey directions of 180°-310° a maximum exists for Nash's winds between 190°-260° with a secondary maximum between 0°-60°. This again corresponds to the axis of the plateau. Nash's winds correspond to Hockey's for directions 310° - 360°. This may be due to either the fact that generally northwest winds are stronger or that the nearest obstruction to the flow from the northwest is more than 0.5 km away.

The Lambert site is located at the base of Copper Ridge (to the southeast of the site) that is aligned 55° to 235°. There are no major obstructions to the air flow within several kilometers to the N or NE. There is a preference for the wind directions at Lambert to be aligned along the axis of the valley. Lambert matches Hockey best for directions of 270°-360° at Hockey. This may be due to the stronger wind speeds encountered with this direction.

The Tower site is located on a plateau (aligned 55°-235°) with a higher ridge approximately (same alignment) 0.4 km to the southeast. A steep downslope is located about 0.2 km to the northwest. There is a slight preference for Tower 30 m winds to be aligned along the plateau; however, Tower 30 m winds generally correspond well with the Hockey 30 m winds. On the average Tower is backed about 10° with respect to Hockey for most wind directions. Tower 10 m winds exhibit a slight preference for directions to be aligned along the plateau axis.

The Johnson site is located near the top of a wide ridge with extremely complex terrain in all directions within a kilometer of the station. There appears to be a preference for wind directions at Johnson to be aligned along Sexton Hollow (which has an axis of 290°-110°), especially for Hockey directions of 270°-360° and as a secondary maximum for Hockey directions of 120°-230°.

There is some evidence of wind channeling caused by the Clinch River valley at the Castlewood station.

POLLUTANT CONCENTRATIONS IN RELATION TO OBSERVED METEOROLOGICAL CONDITIONS

Frequency distributions of the measured SO_2 and NO_x data versus the simultaneous Hockey 30 m level wind directions were generated. These distributions are found in Appendix C. Mean SO_2 concentrations were also computed for each of 12 30° wind direction sectors for each station, using the Hockey 30 m transport winds. Pollution roses were drawn for each station (see Figure 31). All stations show significant impact of the plume for directions coming from the plant. In addition all stations also show elevated concentrations with southwest winds whether the plant is located in this direction or not, leading to the suggestion that higher background levels are associated with this direction than with others.

From an examination of the frequency distribution tables for NO_x in Appendix C, the Hockey 30 m wind direction ranges associated with the highest recorded NO_x readings at each of the stations could be easily obtained. These ranges are listed below along with the direction of the plant from each station:

Station	Hockey 30 m Wind Direction Range Associated with Highest NOx Readings	Direction of Plant from Station
Hockey	260°-320°	287°
Castlewood	200°-240°	58°
Nash's	210°-240°; 260°-300°	244°
Tower	200°-270°	226°
Munsey	190°-230°; 300°-340°	291°
Kent's	210°-250°	248°

Hockey, Nash's, Tower, and Kent's appeared to record high NO_x concentrations with wind directions generally blowing from the direction of the plant. However, Munsey and Castlewood experienced their highest NO_x concentrations with Hockey's 30 m wind directions much different than the direction straight from the plant. These results indicate that terrain-induced flow regimes may be important for transporting the power plant plume to these two stations. Drainage flows occur in the Clinch River Valley, affecting Castlewood, and downslope flow at Munsey may bring the plume down to the Munsey elevation.

The relationships between high SO_2 concentrations at the eight stations and wind speeds and σ_A as recorded at the Hockey 30 m level were investigated. The wind speed ranges and σ_A ranges associated with the high SO_2 values are listed in Table 41. All frequency distributions generated for the pollutant data used the ranges listed below:

0-5	ppb
5-10	"
10-15	"

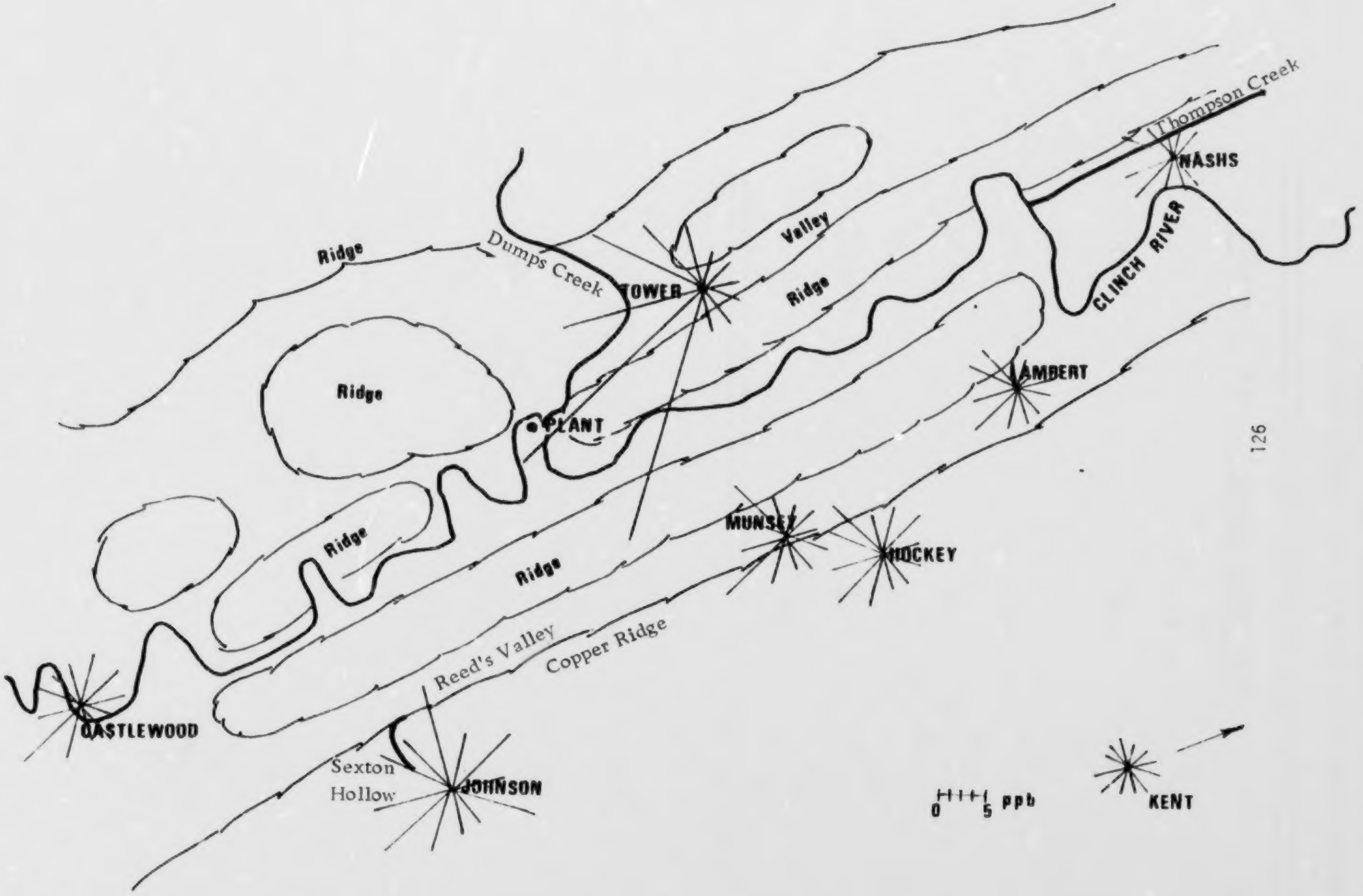
Ridge
Dumps Creek
TOWER
Valley
Ridge
Thompson Creek
NASHS
CLINCH RIVER
Ridge
PLANT
LAMBERT
Ridge
Ridge
MUNSEY
HOCKEY
Reed's Valley
Copper Ridge
CASTLEWOOD
Sexton
Hollow
JOHNSON
0 5 ppb
KENT

Figure 31. SO$_2$ pollution roses.

TABLE 41. WIND SPEEDS AND σ_A RANGES ASSOCIATED WITH HIGHEST SO_2 CONCENTRATIONS

Station	Wind speed (m/sec)	σA (degrees)
Munsey	4-7	0-20
Kent's	4-6	0-10
Castlewood	3-5	0-20
Tower	1-8	0-20
Nash's	2-4	10-30
Lambert	2-4	0-20
Johnson	1-4	0-20
Hockey	1-3	0-70

15-20 "
20-25 "
25-30 "
30-40 "
40-50 "
60-80 "
80-100 "
100-150 "
150-200 " "High" Concentrations
200-300 "
300-500 "

For the purpose of analyzing the meteorological conditions associated with high concentrations, the occurrences in the four highest concentration categories for each station were considered. Munsey, Kent's, and Castlewood showed highest SO_2 readings with moderate wind speeds, while Nash's and Lambert had their highest readings with slightly lighter winds (2-4 m/sec). The ridgetop stations (Johnson and Hockey) had the lightest wind associated with their high SO_2 concentrations. This result supports the finding that high concentrations at the ridgetop stations are associated with nighttime stable conditions as demonstrated in Section 4. The Tower station showed no distinct propensity for any particular wind speed for high concentrations as high values occurred with speeds from 1 to 8 m/sec. The high values with light winds at Tower may be associated with fumigation incidents after nearly calm stable nights, while the higher speeds were most likely associated with the plume passing over the Tower at relatively low heights occurring with neutral conditions.

With the exception of Hockey, the highest SO_2 concentrations occurred with relatively low values of σ_A. At Hockey high values occurred with σ_A as low as the 0°-10° range and as high as the 60°-70° range, indicating the possibility that high values occur with both nearly direct hits by narrow plumes and also in stagnation situations with rather ill-defined plumes. The Kent's results show that the highest SO_2 readings occurred with very small σ_A values (< 10°), indicating that for Kent's to receive a significantly high SO_2 concentration, a very narrow plume was required, which is reasonable since Kent's was the most distant station.

RATIOS OF NO TO NO_2

An important consideration regarding NO_x concentrations in a power plant plume is the rate of conversion of NO to NO_2. Since the oxidation of NO_2 by ozone is a very rapid reaction, but the available ozone supply in any volume of air is low, the formation of NO_2 is highly dependent on the turbulent mixing process which replenishes the supply of ozone in the plume from the ambient air. If there is more turbulence over complex terrain than over flat terrain, it may be evident in the rate of conversion of NO to NO_2. We have not attempted to investigate this question in detail. However, we have computed the ratios of mean NO to mean NO_2 concentrations which were measured at the various fixed monitoring sites for each hour of the day. These ratios are shown in Figure 32 for the Tower and Kent's sites.

A pattern of diurnal variation in the NO to NO_2 ratio is most clearly seen at the Tower site, while hour-to-hour variations are least pronounced for the Kent's site. These two sites are closest and furthest from the plant, respectively. They clearly demonstrate the decrease in the ratio with distance, and thus travel time, from the plant. The mean of 24-hourly ratios is 1.19 at the Tower site and is 0.38 at the Kent's site. If the rate of conversion from NO to NO_2 were proceeding at a constant first-order rate, the ratios at the two sites would be represented by a single exponential decay constant. However, a constant exponential decay for the ratio at the Tower site is over four times the decay constant indicated by the ratio at the Kent's site. It is clear that turbulent mixing rather than the rate of chemical reaction is controlling the rate of conversion by the time the plume reaches the Kent's site.

There is an interesting bulge in NO to NO_2 ratio at the Tower site for the hours of 0800 to 1600. Since wind speeds are normally stronger during daytime hours than during nighttime hours, this would bring the plume to the Tower site faster and with less time to convert NO to NO_2. The bulge begins earlier in the day than the normal increase in wind speed which is most commonly apparent about noon each day. A more detailed examination of the relationship of the ratio to wind speed is warranted to better explain this phenomenon.

CASE STUDIES

Periods of high hourly average concentrations at the fixed monitoring stations were examined as possible case study periods. From this list, eight case study periods were chosen for detailed plume behavior analysis based on their apparent applicability to other complex terrain sites. Table 42 provides a listing of the case study periods along with a brief description of plume behavior for each.

Each case study is described in detail with special emphasis on the interaction of the plume with terrain features and the meteorology that influenced the plume behavior. Tables containing pertinent parameters for a period of 5 hours before to 5 hours after the pollution episode are provided for each case study. Table 1 should be referenced for locations and elevations of the fixed stations.

Case Study I (2300 EST, December 21, 1976 - 0200 EST, December 22, 1976)

High SO_2 concentrations were recorded at both Hockey and Munsey for the same hour period during this case study (see Table 43). Both stations have approximately the same bearing from the plant with Hockey on the crest of Copper Ridge and Munsey on the side of the ridge facing the plant.

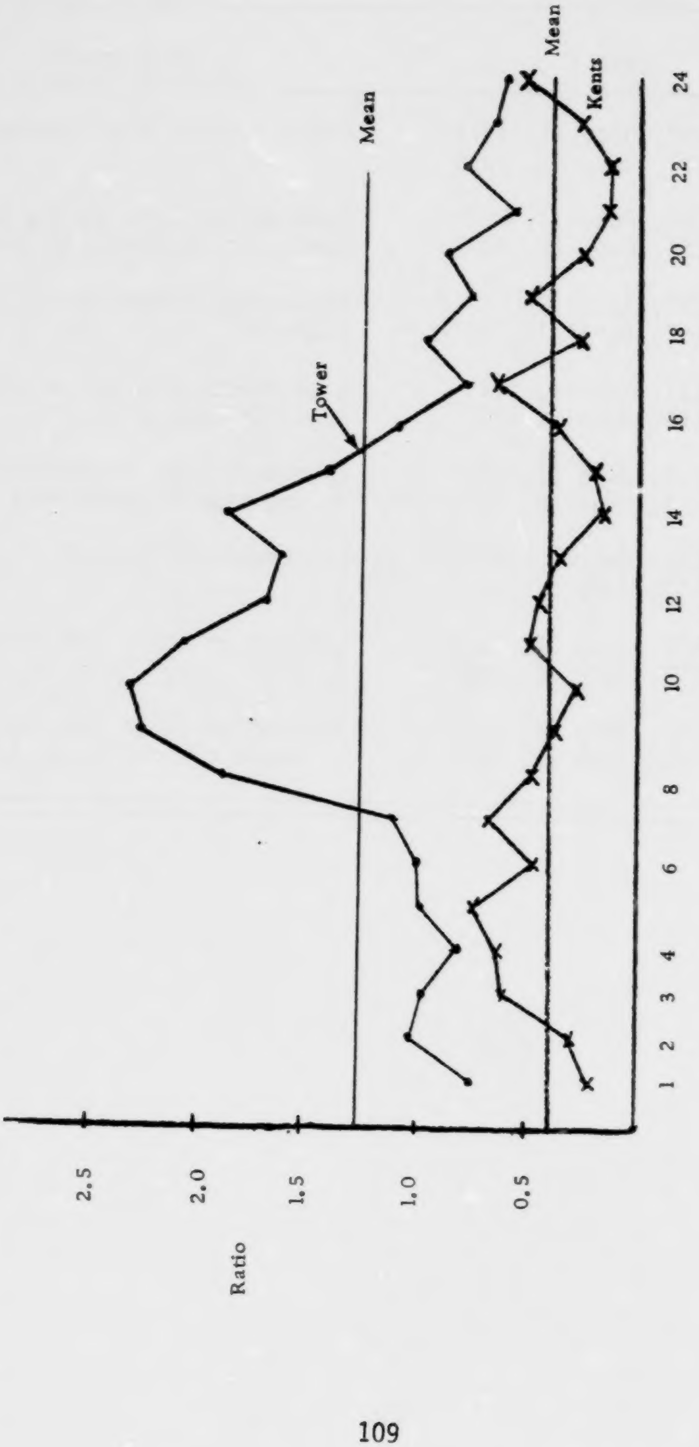

Figure 32. Ratio of NO to NO_2 Concentration.

TABLE 42. LIST OF CASE STUDIES

Case study number	Date	Description
I	2300 EST, Dec. 21, 1976 - 0200 EST, Dec. 22, 1976	Plume rose to cross Copper Ridge
II	0800 EST, Feb. 11, 1977 - 1400 EST, Feb. 11, 1977	Down-valley flow during morning, stable conditions followed by plume fumigation
III	1000 EST, April 19, 1977 - 1500 EST, April 19, 1977	Prolonged fumigation at lower elevation stations
IV	1000 EST, May 15, 1977 - 1200 EST, May 15, 1977	High concentrations on ridge during unstable conditions
V	0400 EST, June 30, 1977 - 0500 EST, June 30, 1977	Extremely high concentrations on ridge during stable conditions
VI	0700 EST, July 6, 1977 - 1000 EST, July 6, 1977	Prolonged fumigation
VII	0900 EST, July 24, 1977 - 1700 EST, July 24, 1977	Helicopter cross sections, plume rose to cross ridge
VIII	1100 EST, July 26, 1977 - 1700 EST, July 26, 1977	Helicopter cross section, lower portion of plume channelled by terrain

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TABLE 43. CASE STUDY I DATA

		SO$_2$ Hourly Average/Peak (ppb)							Plume Ht.* (m)	Hockey WS-30m (m/sec.)	Hockey WD-30m (deg.)	Hockey σ_θ-30m (deg.)	Hockey WS-10m (m/sec.)	Hockey WD-10m (deg.)	Hockey σ_θ-10m (deg.)	Mooney WS-10m (m/sec.)	Mooney WD-10m (deg.)	Mooney σ_θ-10m (deg.)	Tower σ_θ-30m (deg.)	Tower ΔT(30-0.5m) (°C)	** Stability	SO$_2$ Plant Emission (g/sec.)
Date	Hour	Tower	Hockey	Kents	Castle	Lambert	Mooney	Hale														
Dec. 21	18	5/5	11/27	0/0	5/5	11/11	14/27	0/0	571	6.6	321	8.1	2.9	307	16	1.6	317	27	11.4	0.4	5	791
•	19	5/5	8/27	0/0	7/15	11/18	0/7	0/6	569	5.2	310	7.6	2.7	297	12	1.0	310	69	8.3	0.9	5	791
	20	5/5	11/27	0/0	8/27	15/18	0/0	0/0	303	5.4	311	6.0	3.1	295	10	0.7	301	90	16.4	1.5	6	797
	21	5/5	5/5	0/0	7/15	16/18	0/7	0/0	282	4.5	303	6.0	2.9	298	11	0.4	166	52	--	1.8	6	814
	22	6/16	6/27	0/0	7/7	15/18	0/0	0/0	283	3.5	312	5.2	2.0	295	9	1.2	125	17	19.0	1.8	6	809
	23	5/5	95/206	0/0	7/7	12/18	21/67	--	267	3.9	315	6.7	1.9	307	8	1.0	128	19	22.4	2.3	6	794
	24	5/5	190/217	0/0	7/7	10/10	85/97	--	193	--	--	--	1.9	301	11	1.0	126	30	--	2.9	6	799
Dec. 22	1	5/5	118/184	0/0	7/7	10/10	44/71	--	272	2.1	302	9.3	1.1	290	23	0.4	115	56	--	2.1	6	768
	2	5/5	150/217	0/0	7/7	10/10	119/127	--	267	2.1	279	22.9	1.5	282	12	0.3	102	70	31.7	2.0	6	790
	3	7/16	5/5	0/0	7/15	10/10	33/47	--	290	2.3	218	10.3	1.9	179	11	0.1	118	80	--	1.5	6	770
	4	1/5	5/5	0/0	6/6	10/10	6/17	--	219	2.3	204	8.7	2.0	172	18	0.1	118	67	22.4	1.4	6	780
	5	5/5	5/5	0/0	7/7	15/17	9/17	--	199	4.6	213	5.0	3.3	189	7	0.2	130	58	--	1.1	6	697
	6	8/28	5/5	0/0	7/7	17/17	5/7	--	201	5.2	210	11.3	4.2	196	14	0.3	108	83	11.7	1.5	6	755
	7	7/16	10/16	0/0	9/15	13/17	0/0	15/69	208	5.8	201	5.4	4.2	177	9	0.1	140	94	--	1.5	6	740

* Calculated from average heat flux of the 2 stacks.

** Based on bulk Richardson number classification; see text on page 190.

This case study occurred within an 11-hour period in which Upper Hockey wind directions shifted from 321° at 1800 EST on December 21 to 204° at 0400 EST on December 22. The weather was being influenced on the synoptic scale by a high pressure system centered over South Carolina. During the case study Hockey 30 m wind speeds ranged from 2.1 m/s to 3.9 m/s and wind directions from 279° to 315°. These wind directions would have transported the plume in the general direction of both Hockey and Munsey. However, as illustrated in Figures* 33 to 35, the plume position based on the 30 m 2-minute wind vectors at Hockey are southwest of both the Hockey and Munsey sites. The calculated plume heights for the case study period indicate that the plume centerline was approximately 90 m to 170 m below the 30 m Hockey level. Wind directions at the 10 m Hockey level compared to the 30 m level show that the winds were veering with height. Therefore, during this case study, the 30 m Hockey wind data did not accurately estimate the position of the plume; the estimated plume position was veered with respect to the actual.

During this case study the DT3 (30 m temperature - 0.5 m temperature) values at Tower were strongly positive resulting in the stability classification to be very stable. The calculated plume heights were relatively low, ranging from 195 m to 272 m above plant base. These plume heights would have resulted in the plume centerline being located approximately halfway between Hockey and Munsey in the vertical. However, the SO_2 concentrations at Hockey averaged about twice as high as the concentrations at Munsey. Therefore, the plume centerline probably rose to cross Copper Ridge. Wind directions of approximately 120° recorded at Munsey indicate the existence of downslope flow on Copper Ridge. This flow may have entrained the lower portion of the plume resulting in the elevated concentrations observed at Munsey.

Case Study II (0800-1400 EST, February 11, 1977)

During this case study (see Table 44) elevated SO_2 hourly average concentrations were reported simultaneously at Castlewood, Lambert, Munsey, Tower, and Nash's. A high pressure system off the South Carolina Coast was influencing the weather pattern over soutwest Virginia. A pibal without T-sonde launched at 1017 EST showed the wind flow at 100 m above plant base to be light and from a direction of 86°; at approximately 320 m the wind speed was 4 m/s and the direction had veered sharply to 223° (Figure 36 and 37). Winds at the 30 m level at Hockey were relatively consistent during this period. Wind speeds ranged from 3.2 m/sec to 5.1 m/s, wind directions ranged from 213° to 232°, and sigma azimuths ranged from 4.7° to 10.9°. Wind speeds at Castlewood were very light and therefore the wind directions were probably not very indicative

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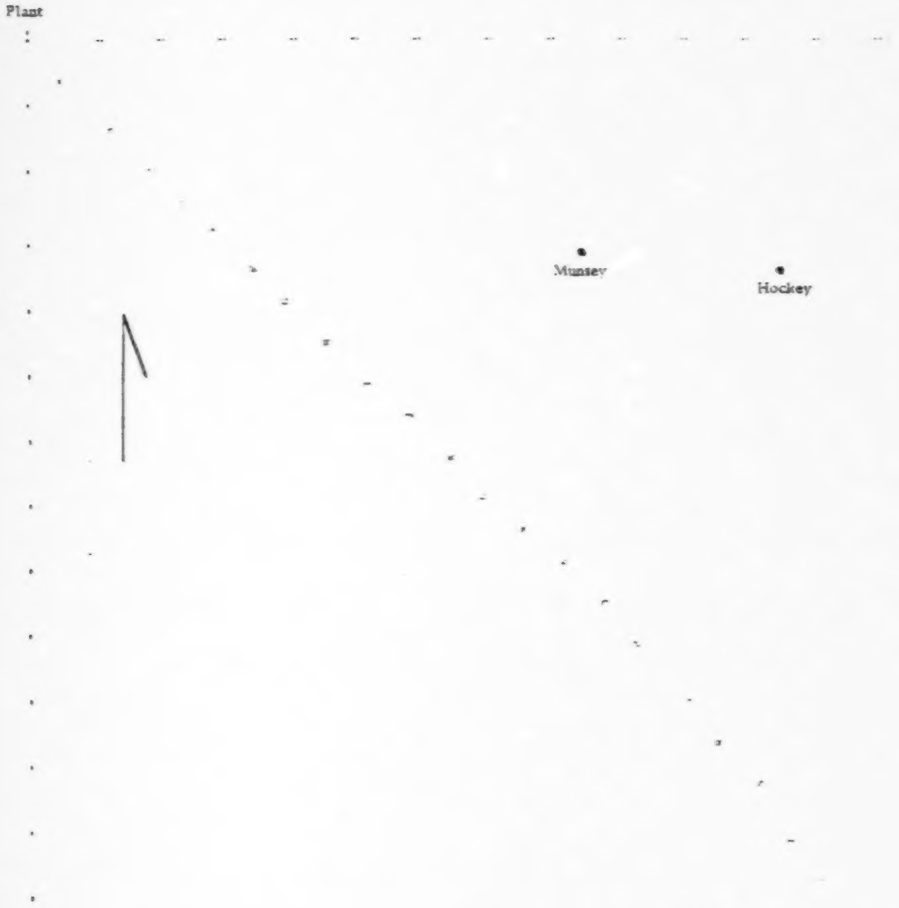
*NOTE: Figures 33 to 35 and 43 to 58 show snapshots of the plume at the indicated time. Each lettered point represents an increased travel increment of 2 minutes. Point A is the location of material which left the stack 2 minutes earlier; Point B is the location of material which left the stack 4 minutes earlier, etc.



Plant
Munsey
Hockey

Figure 33. Configuration of plume at 2300 EST, December 21, 1976

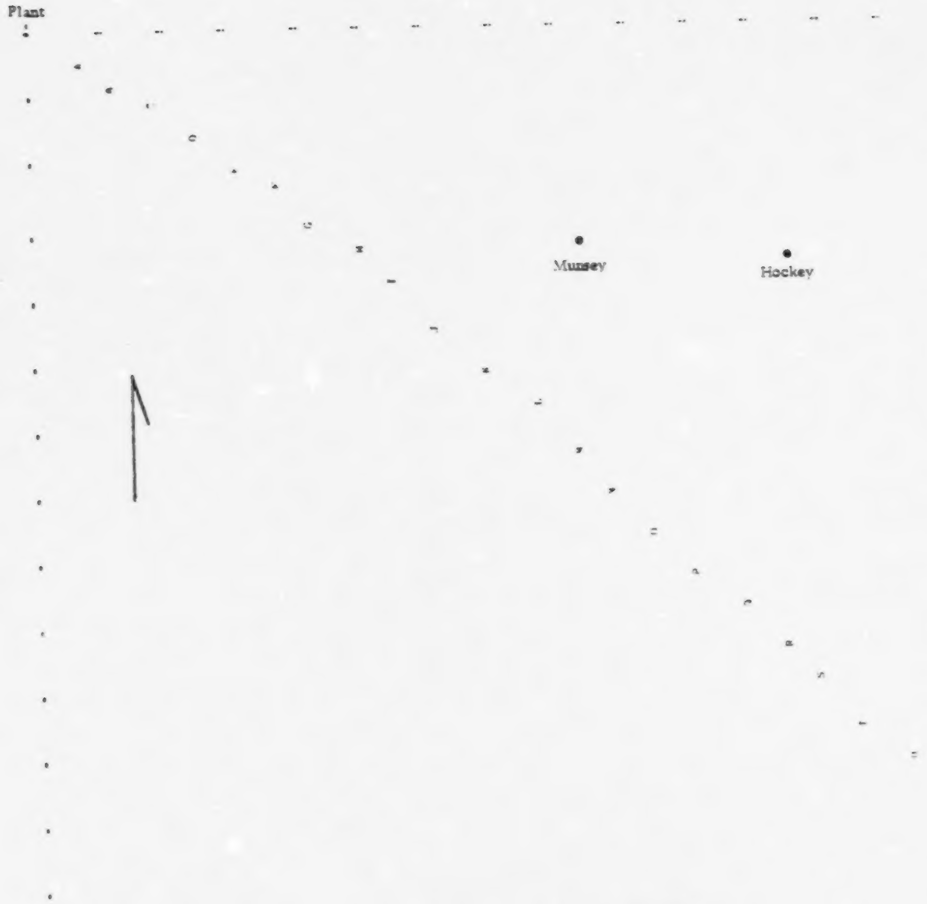

Plant
Munsey
Hockey

Figure 34. Configuration of plume at 2400 EST, December 21, 1976

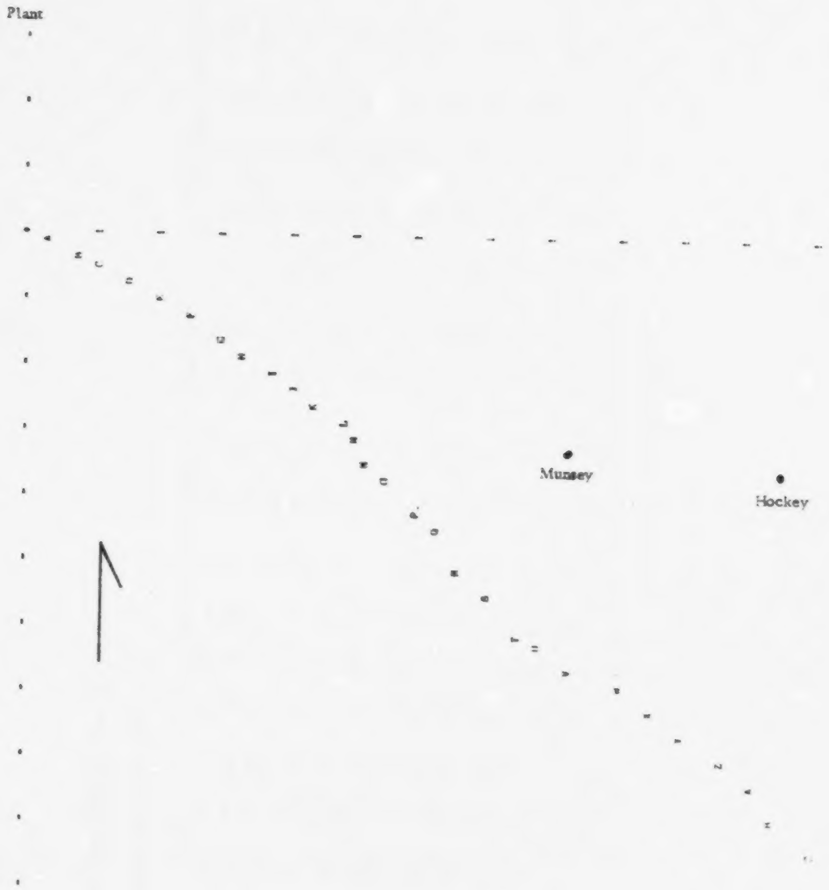


Figure 35. Configuration of plume at 0100 EST, December 22, 1976

TABLE 44. CASE STUDY II DATA

		SO_2 Hourly Average/Peaks (ppb)																				
Date	Hour	Tower	Hochey	Kenns	Castle	Lambert	Johnson	Murray	Hashe	Plume Ht.* (m)	Hochey WS-30m (m/sec.)	Hochey WD-30m (deg.)	Hochey σ_A 30m (deg.)	Castle WS-10 m (m/sec)	Castle WD-10 m (deg.)	Castle σ_A - 10 m (deg.)	Lambert WS-10 m	Lambert WD-10 m	Lambert σ_A -10 m	Tower σ_A 30m (deg.)	Tower ΔT(30-0.5 m) (°C)	Stability**	SO_2 plant emissions (g/sec)
Feb. 11	3	6/6	18/27	0/0	6/6	0/4	13/27	17/18	0/0	243	5.9	214	7.5	0.2	302	42	0.8	73	18	--	1.8	6	1237
	4	6/6	7/16	0/0	6/6	0/0	6/7	9/18	0/0	290	5.7	211	8.1	0	309	91	0.7	73	35	--	1.9	6	1234
	5	6/6	29/48	0/0	12/16	0/4	5/17	7/8	0/0	302	6.0	215	7.3	0.2	249	38	0.5	92	54	18.3	1.7	6	1257
	6	6/6	37/48	0/0	25/27	0/4	22/27	7/8	0/0	231	4.6	218	4.7	0.4	301	40	0.6	82	90	22.4	1.5	6	1241
	7	6/6	5/16	0/0	47/69	0/4	8/17	15/29	0/0	199	4.5	222	4.7	0.5	258	29	0.7	85	18	--	1.4	6	1234
	8	6/6	4/5	0/4	75/164	3/11	0/0	22/29	0/0	235	6.0	222	7.1	0.5	239	20	0.7	94	50	--	1.0	6	1215
	9	7/-	4/-	0/-	122/-	0/-	0/-	16/-	0/-	197	5.5	213	10.9	0.4	239	41	0.4	100	31	31.6	1.0	6	1212
	10	14/27	4/5	16/42	141/185	6/11	0/0	24/150	0/0	231	4.2	224	4.7	0.1	116	98	1.1	95	53	12.2	0.4	6	1246
	11	134/215	4/5	16/30	117/153	48/98	0/0	70/81	0/11	218	5.8	227	8.8	0.1	17	84	0.3	223	73	10.7	0.3	6	1216
	12	144/257	4/5	2/6	135/174	70/80	0/7	52/71	50/69	212	4.7	232	10.9	0.6	104	33	0.9	262	35	10.3	0.3	5	1210
	13	78/173	4/5	0/0	54/90	44/66	0/0	36/60	56/80	268	5.1	291	10.5	0.8	290	78	1.8	265	20	11.0	0	5	1258
	14	109/247	4/5	1/4	24/27	13/19	0/0	9/18	12/23	473	5.1	227	8.4	1.2	278	45	2.7	272	12	14.0	-0.2	4	1277
	15	41/142	4/5	0/3	12/16	8/11	0/0	0/0	7/12	266	4.8	233	12.1	1.7	236	47	2.0	266	10	10.4	-0.3	4	--
	16	50/111	3/5	0/9	12/16	0/4	0/0	0/0	0/0	241	6.6	228	8.0	1.6	244	57	2.3	268	21	13.4	-0.1	4	--
	17	21/37	4/5	0/0	16/16	2/4	0/0	0/0	0/0	465	5.9	229	9.1	0.9	237	97	3.1	254	15	10.7	0.2	4	--
	18	18/27	4/5	0/0	17/17	5/11	0/7	0/0	0/0	442	4.4	228	6.1	0.2	202	88	1.5	229	18	9.5	1.0	5	--
	19	17/17	4/5	0/0	7/16	18/25	8/17	0/8	0/0	417	4.4	238	2.8	0.3	308	65	1.3	280	38	11.8	1.7	6	--

* Calculated from average heat flux of the 2 stacks.

** Based on bulk Richardson number classification; see text on page 190.

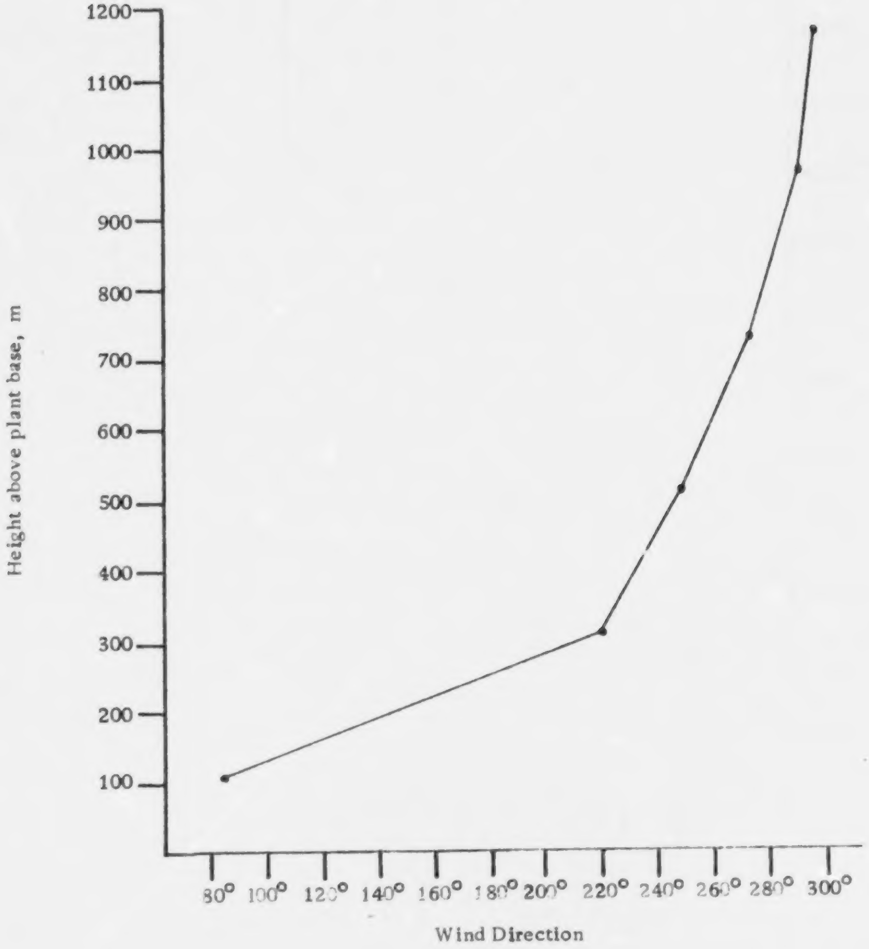


Figure 36. Wind Direction profile at 1017 EST February 11, 1977, at the power plant.

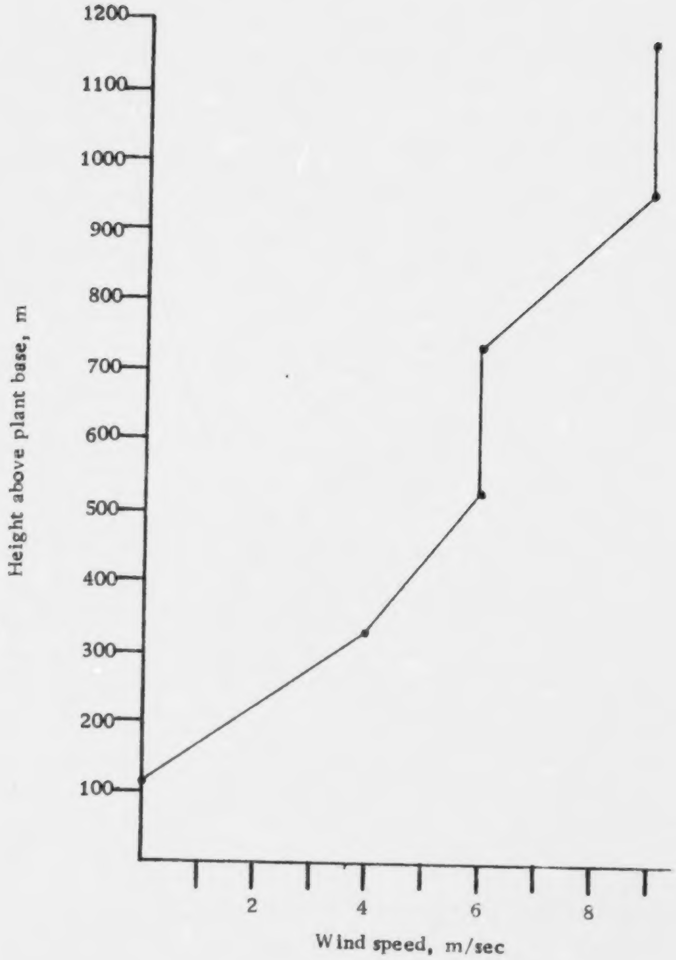


Figure 37. Wind speed (m/s) profile at 1017 EST, February 11, 1977, at the power plant.

of the plume flow. The calculated plume heights, with the exception of hour 1400 EST, were relatively low, ranging from 197 m to 268 m. The stability was computed to be very stable on hours 0800 to 1100 EST, slightly stable on hours 1200 to 1300 EST, and neutral on hour 1400 EST.

From hours 0800 to 1000 EST the elevated SO_2 concentrations were confined to Castlewood. This may be an indication that the plume was entrained in a downvalley flow along the Clinch River Valley to Castlewood. From hours 1100 through 1400 EST, SO_2 concentrations at Castlewood decreased while significant SO_2 concentrations were reported at Tower, Nash's, Lambert, and Munsey. This may be the result of a prolonged fumigation incident that occurred in the valleys surrounding the plant. In this case, a very intense inversion existed between Nash's elevation and Hockey at 0900 EST and between Castlewood and Hockey for 1000 and 1100 EST (see Figure 38).

Case Study III (1000 EST - 1500 EST, April 19, 1977)

This case study is a typical example of an event that occurred frequently during the late morning hours in the vicinity of the Clinch River plant. As evidenced by Tables 12 to 19 in Section 4, the lower elevation stations (i.e., Tower, Castlewood, Munsey, Lamberts and Nashs) show a preference for high SO_2 concentrations between the hours of 0900 EST and 1400 EST. This phenomenon is less pronounced at the higher elevation stations (i.e., Kents, Hockey, and Johnson). Often a number of fixed monitoring stations at different bearings simultaneously recorded significant concentrations during the late morning hours.

In this case study, elevated concentrations of SO_2 (see Table 45) were recorded between 1100 EST and 1300 EST at Tower, Lambert, Munsey and Nashs. The weather at Clinch River was being synoptically influenced by a high pressure system off the North Carolina Coast. The DT3 values at Tower for 0600 EST to 0900 EST indicate the existence of a ground-based inversion. This inversion probably extended to a point above the lower elevation stations and inhibited vertical dispersion and plume rise. This is supported by the calculated plume heights for 0600 EST to 0900 EST which ranged from 225 m to 232 m. As a result of the local flows within the inversion, the plume was advected through the valleys and mountain gaps surrounding the plant (Figure 39). The DT3 values for the period of 1100 EST to 1300 EST indicate the inversion was dissipating from the ground up. This eventually resulted in an elevated inversion above plume height, therefore producing a fumigating plume. By 1300 EST the elevated inversion was dissipating, bringing a conclusion to the fumigation episode. This is supported by a pibal/T-sonde launched at 1228 EST which showed a nearly adiabatic lapse rate (see Figures, 40, 41 and 42).

To more fully study this prolonged fumigation phenomenon at complex terrain sites, an extensive pibal/T-sonde network would be needed (i.e., launch sites in a number of valleys and on ridge tops) with launchings

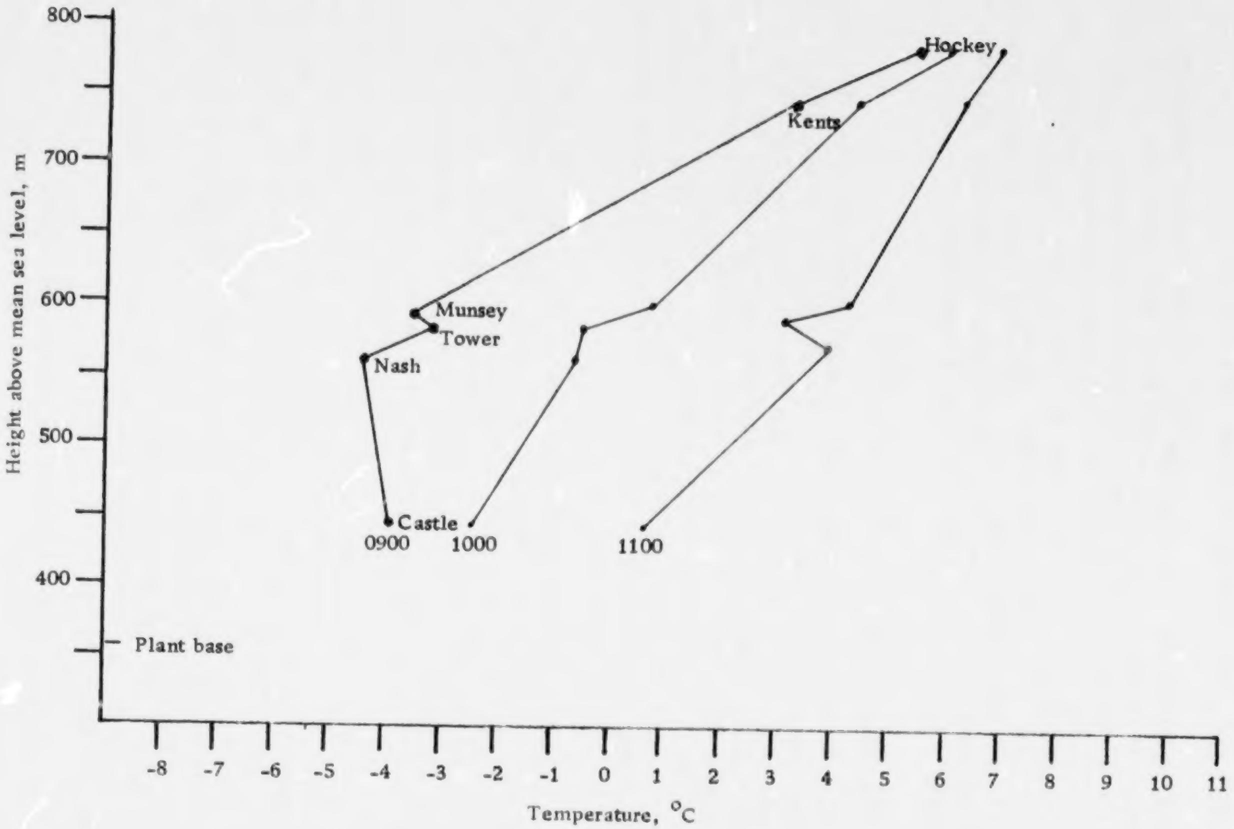


Figure 38. Temperature profile based on fixed ground station temperatures - February 11, 1977.

TABLE 45. CASE STUDY III DATA

		SO_2 Hourly Average/Peak (ppb)								Hockey	Hockey	Hockey	Tower	Tower		SO_2 Plant
Date	Hour	Tower	Hockey	Kents	Lambert	Johnson	Munsey	Nashs	Plume Ht.* (m)	WS-30m (m/sec.)	WD-30m (deg.)	$\sigma_{\wedge}$-30m (deg.)	σ_E-30m (deg.)	ΔT(30-0.5m) (°C)	Stability**	Emission (g/sec.)
Apr. 19	6	3/3	5/5	0/0	0/0	4/4	0/0	0/5	225	3.7	210	8	13.6	1.6	6	329
	7	3/3	5/5	0/0	0/0	4/15	0/7	0/5	228	3.7	204	5	6.3	1.7	6	342
	8	3/3	5/5	0/0	0/0	9/15	0/7	0/17	227	3.5	199	7	14.2	1.4	6	345
	9	3/3	5/5	0/0	--	15/15	6/16	0/5	232	2.5	210	10	2.1	0.6	6	343
	10	3/3	5/5	0/0	15/19	13/15	38/81	0/17	384	1.1	211	30	2.1	0.3	6	342
	11	90/192	5/5	0/0	20/32	--	40/91	30/53	272	1.1	244	43	17.4	-0.1	6	342
	12	159/286	5/5	0/0	71/147	8/15	10/16	37/53	309	2.2	309	19	19.7	-0.6	1	332
	13	30/119	5/5	0/0	12/32	7/15	7/7	18/65	370	2.0	282	46	17.7	-1.1	3	336
	14	22/77	5/5	0/0	0/5	4/4	6/7	5/5	395	1.1	212	72	16.1	-0.8	3	340
	15	3/3	5/5	0/0	0/0	58/174	2/7	0/5	370	3.4	2	35	20.4	-0.2	4	338
	16	3/3	5/5	0/0	0/0	8/68	1/7	0/5	301	3.2	7	21	27.4	-0.1	5	340
	17	3/3	5/5	0/0	0/0	5/15	0/7	0/5	371	4.2	100	62	24.7	-0.1	5	340
	18	3/3	5/5	0/0	0/18	4/4	0/0	0/5	390	6.7	130	7	13.3	0	4	340

* Calculated from average heat flux of the 2 stacks.

** Based on bulk Richardson number classification; see text on page 190.

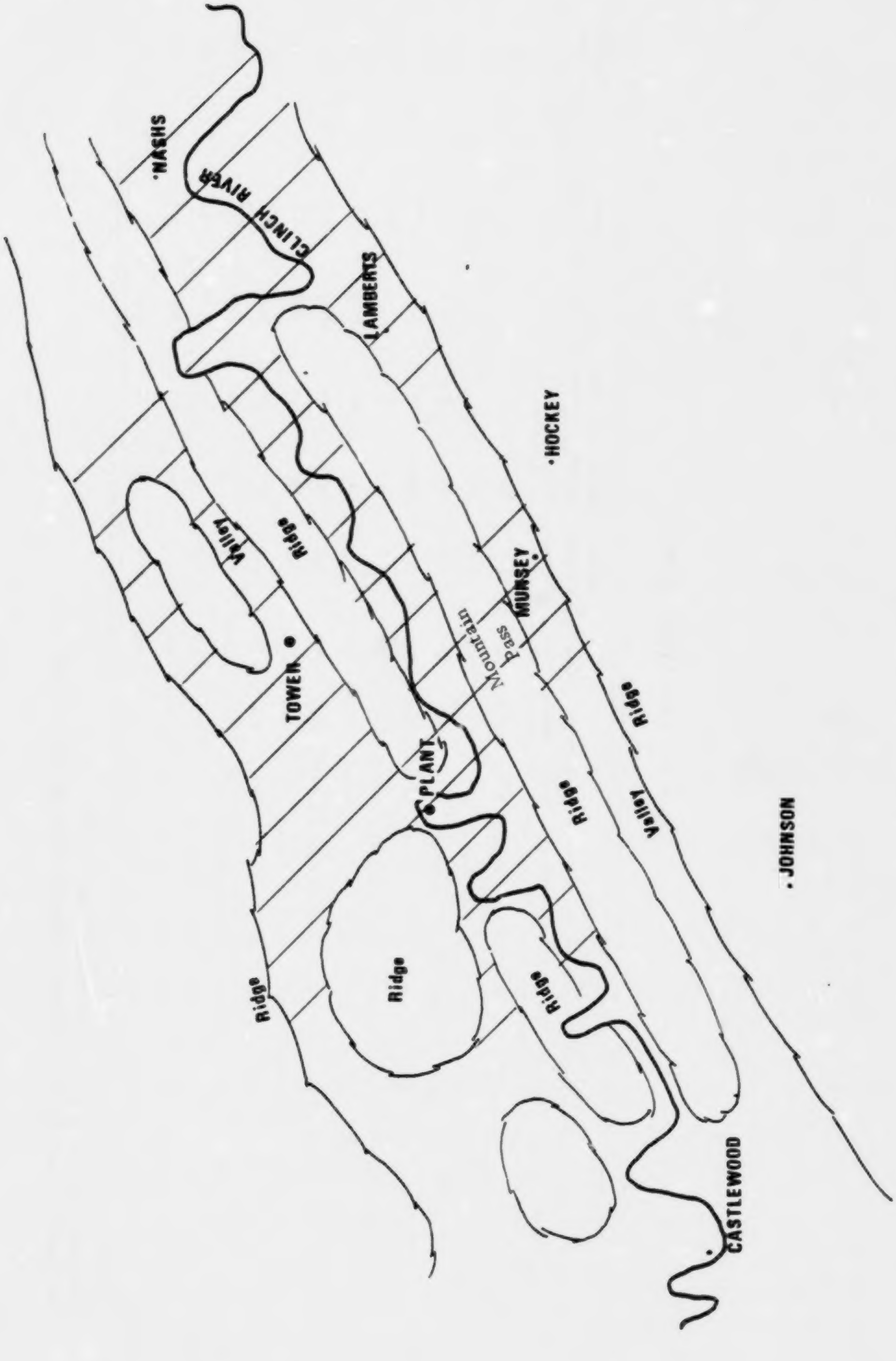

NASHS
CLINCH RIVER
LAMBERTS
HOCKEY
Valley
Ridge
TOWER
MUNSEY
Mountain pass
Ridge
PLANT
Ridge
Valley
JOHNSON
Ridge
Ridge
Ridge
CASTLEWOOD

Figure 39. Location of fumigating plume (slash lines) on April 19, 1977.

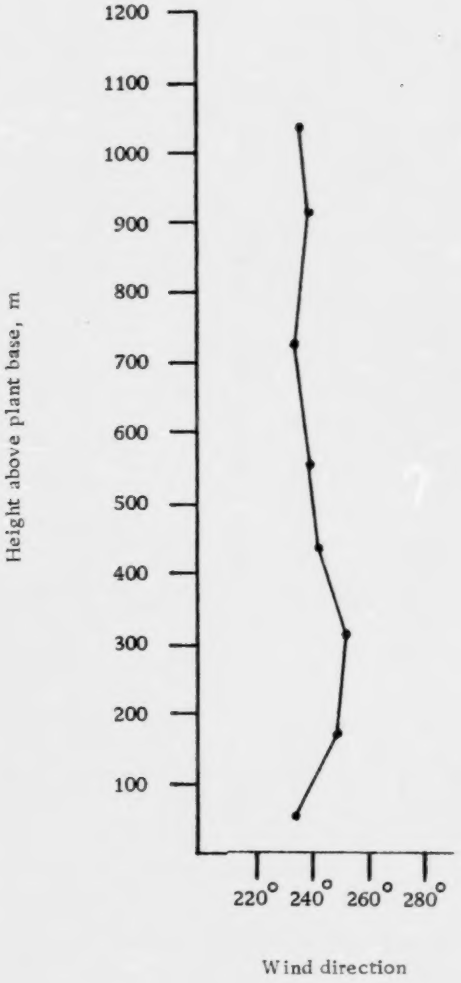


Figure 40. Wind direction profile at 1228 EST, April 19, 1977, at the power plant.

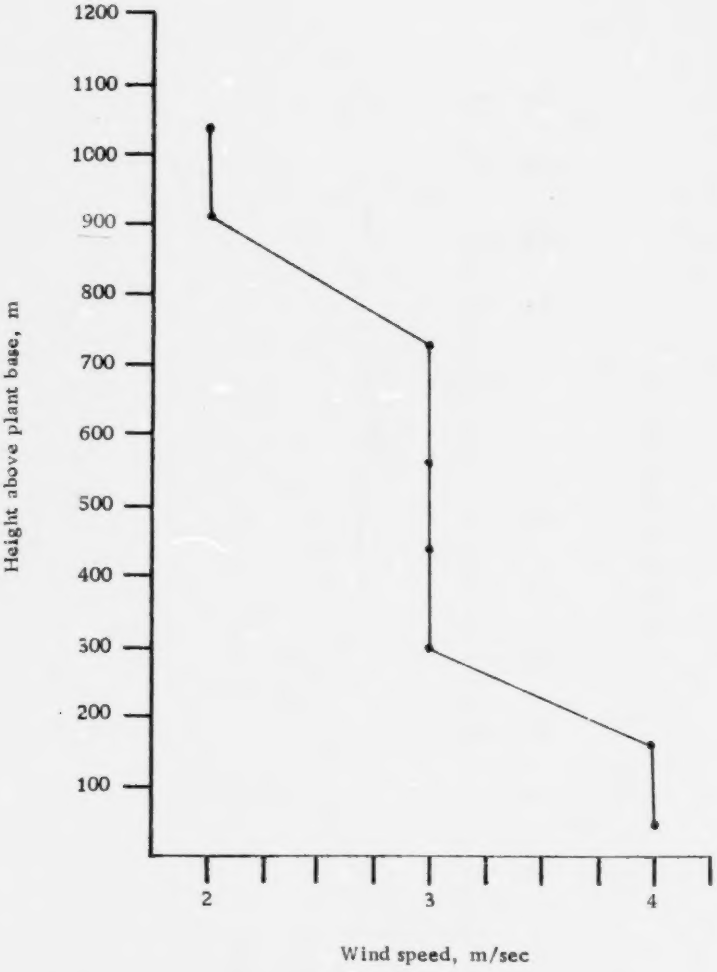


Figure 41. Wind speed profile at 1228 EST, April 19, 1979, at the power plant.

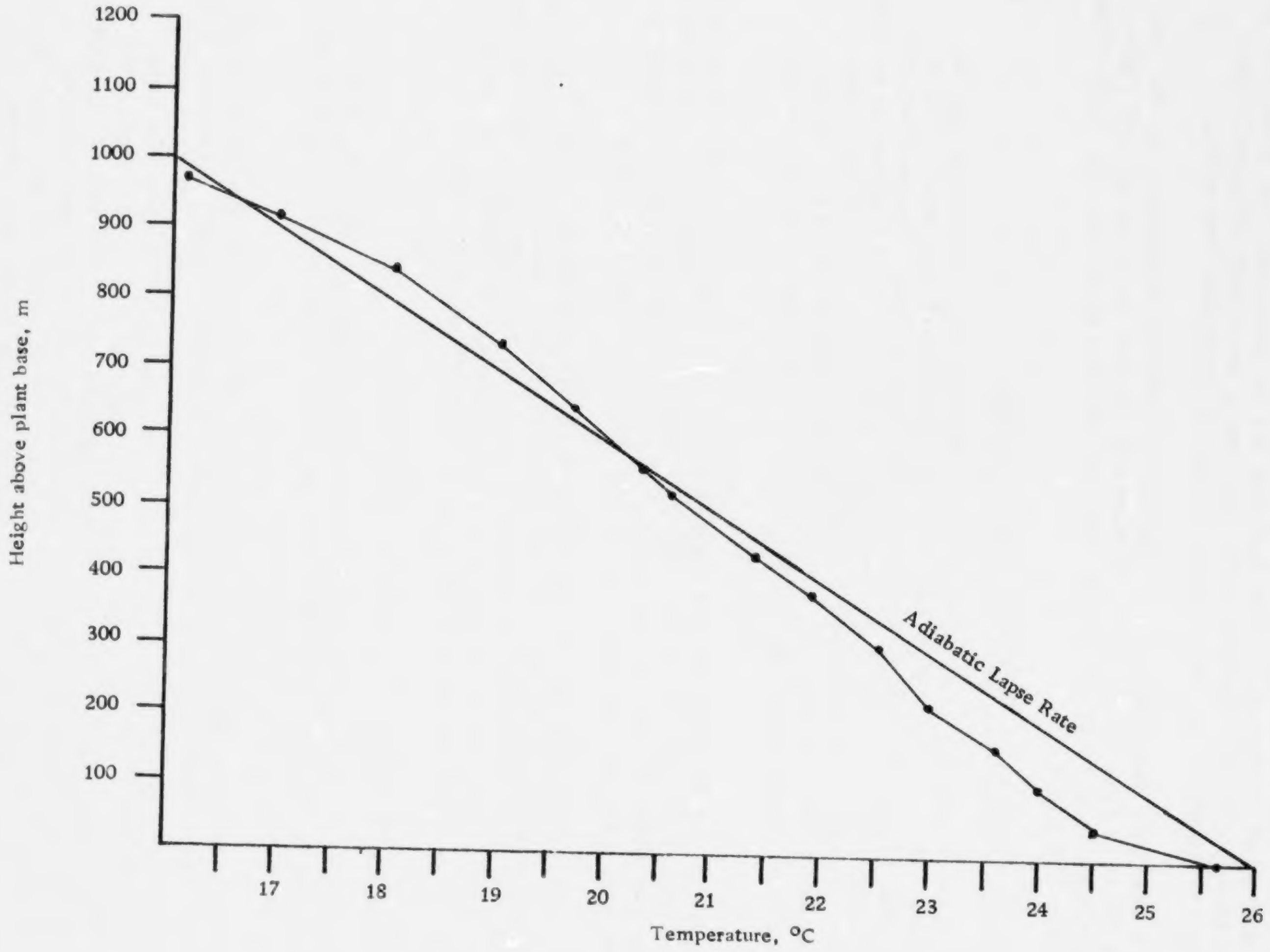


Figure 42. Temperature (°C) profile at 1228 EST, April 19, 1977, at the power plant.

every 1/2 hour commencing at daybreak. In this way, an accurate account of the behavior of the inversion and the local wind flow could be documented. However, one of the problems encountered during the Clinch River Field Project was the propensity of fog to form in the river valley overnight. Often the fog would not dissipate until late morning. Obviously, this restricted the number of pibal launchings during these hours. An acoustic sounder might have been one method of sidestepping the fog problem in obtaining the structure of the temperature profile. Perhaps wind data could have been obtained from a meteorological tower of at least stack height located near the plant.

There are many questions as to how such a complex phenomenon as the one described in this case study could be modeled, as the location of the fumigation episodes is a function of the terrain configuration and the local flows transporting the plume.

Case Study IV (1000 EST - 1200 EST, May 15, 1977)

This case study included several hours of high SO_2 concentrations at Johnson (see Table 46), a ridge top station; no other fixed monitoring station reported elevated concentrations during this period. The weather over southwest Virginia was being influenced by a weak cold front moving down from the north. Hockey 30 m wind speeds ranged from 1.4 m/s to 2.2 m/s, wind directions from 359° to 15°, and sigma azimuths from 35° to 45°. These wind directions would have carried the plume in the general direction of Johnson.

Figures 43 to 49 show the configuration of the plume based on 2-minute wind data from Hockey at specific times between 1000 EST and 1100 EST. Table 47 provides the 2-minute SO_2 concentrations for the same time period. It appears the plume swept by the Johnson site during the course of the hour.

For this case study period the calculated plume heights ranged from 367 m to 443 m above plant base or approximately 150 m above the Johnson site. The stability classification was slightly unstable for 1000 EST. Due to the unstable conditions, the high concentrations observed at Johnson could be explained by a large vertical dispersion or looping of the plume.

Case Study V (0400-0500 EST, June 30, 1977)

This case study involves the highest hourly average SO_2 concentration measured at Hockey (see Table 48); no other fixed monitoring station reported an elevated SO_2 concentration.

The weather over southwest Virginia was influenced by a high pressure ridge over the Middle Atlantic states and a stationary front extending from Iowa to North Carolina. The 30 m wind speeds were 1.2 m/s and wind directions were 278° and 233° with sigma azimuths of 24° and 37°. Hockey 10m wind speeds were very light and hence directions were probably not indicative of the plume transport direction. Plume heights were computed to be approximately 300 m and the stability class was determined to be very stable. The relatively small wind elevation sigmas (σ_E) observed at the Tower 30 m level may indicate that the vertical extent of the plume was narrow, i.e., vertical dispersion was small.

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TABLE 46. CASE STUDY IV DATA

Date	Hour	SO$_2$ Hourly Average/Peak (ppb) Tower	Hockey	Kents	Lambert	Johnson	Munsey	Nashs	Plume Ht.* (m)	Hockey WS-10m (m/sec.)	Hockey WD-30m (deg.)	Hockey σ_A-30m (deg.)	Johnson WS-10m (m/sec.)	Johnson WD-10m (deg.)	Johnson σ_A-10m (deg.)	Tower σ_E-30m (deg.)	Tower ΔT(30-0.5 m) (°C)	Stability**	SO$_2$ Plant Emissions (g/sec.)
May 15	5	4/4	0/6	0/0	0/4	7/9	0/1	2/4	255	1.2	236	22	0.6	265	12	8.8	1.8	6	848
	6	4/4	1/6	0/0	0/0	0/0	0/1	2/4	211	1.5	226	11	0.9	267	17	6.1	1.2	6	811
	7	4/4	0/6	0/0	0/0	0/0	0/1	4/4	214	1.1	256	10	0.8	266	14	6.4	0.3	6	795
	8	4/4	0/6	0/0	0/0	0/9	0/1	2/4	243	0.9	311	14	0.8	94	64	17.0	-0.3	4	864
	9	8/14	0/6	0/0	0/4	3/9	1/1	2/4	255	1.0	342	29	1.6	92	17	27.2	-0.1	6	931
	10	6/14	4/6	0/0	3/4	67/242	1/1	4/16	413	1.6	15	38	1.4	108	38	37.2	-0.3	3	868
	11	3/M	1/M	0/M	1/M	136/M	1/1	4/4	443	1.4	359	45	1.2	112	51	38.4	-0.4	1	877
	12	3/3	0/6	0/0	0/4	37/53	1/1	4/4	367	2.2	14	45	1.1	117	67	25.0	-0.9	1	824
	13	3/3	0/6	0/0	0/0	7/20	1/1	2/4	313	2.2	358	37	2.3	81	45	24.9	-1.2	2	830
	14	3/3	2/6	0/0	0/0	0/0	1/1	4/4	255	3.7	346	25	2.2	83	43	22.5	-1.3	2	803
	15	3/3	0/6	0/0	0/0	0/0	1/1	4/4	315	3.1	340	20	1.9	113	41	25.8	-1.3	2	780
	16	3/3	4/6	0/0	0/0	0/0	1/1	4/4	454	4.6	355	17	2.5	98	24	22.9	-1.3	2	791
	17	3/3	2/6	0/0	0/0	0/0	0/1	4/4	476	4.3	5	22	2.2	106	29	19.6	-0.8	3	790

* Calculated from average heat flux of the 2 stacks.

** Based on bulk Richardson number classification; see text on page 190.

M - designates missing value

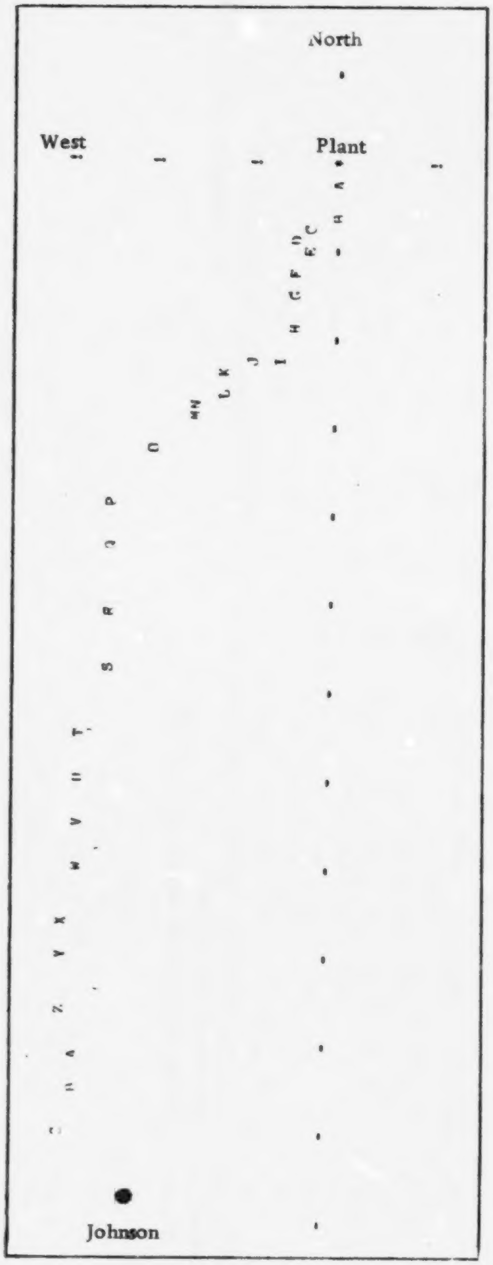

Figure 43. Calculated configuration of plume at 1000 EST, May 15, 1977.

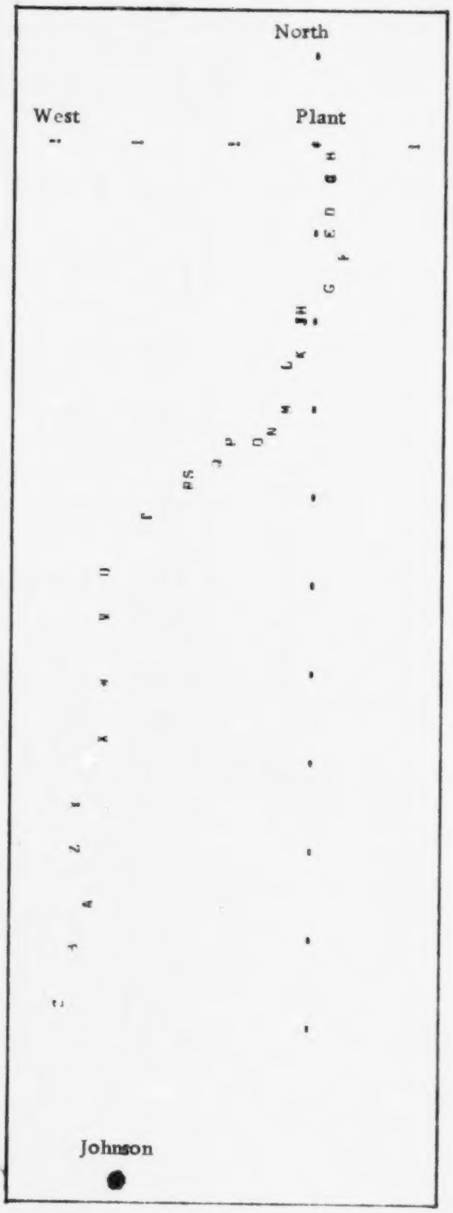

Figure 44. Calculated configuration of plume at 1010 EST, May 15, 1977.

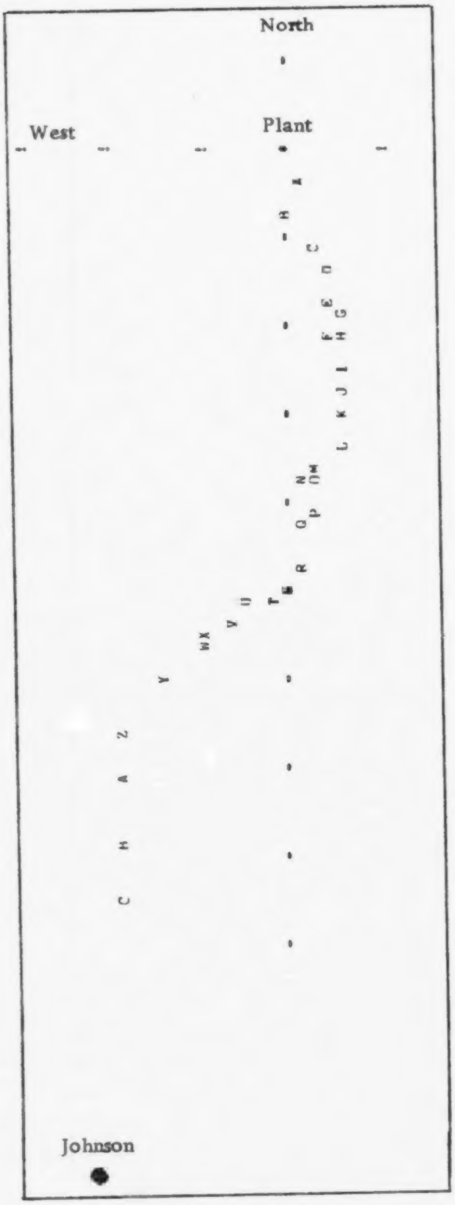

Figure 45. Calculated configuration of plume at 1020 EST, May 15, 1977.

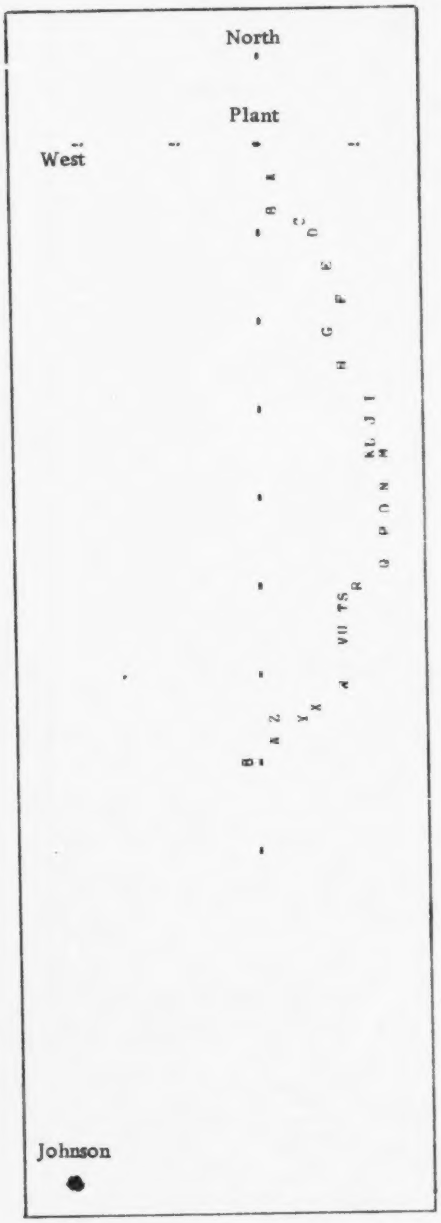

Figure 46. Calculated configuration of plume at 1030 EST, May 15, 1977.

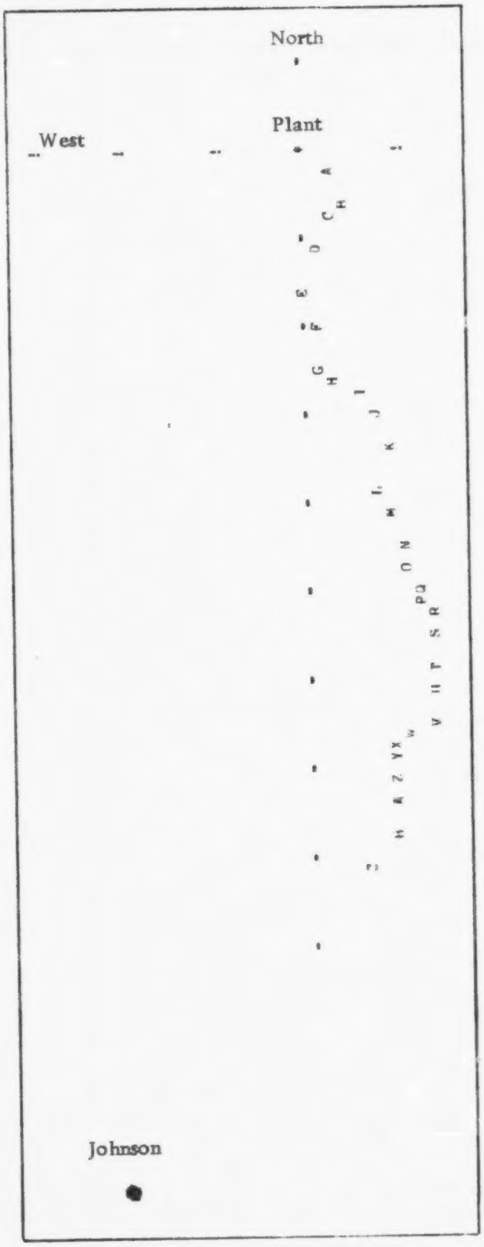

Figure 47. Calculated configuration of plume at 1040 EST, May 15, 1977.

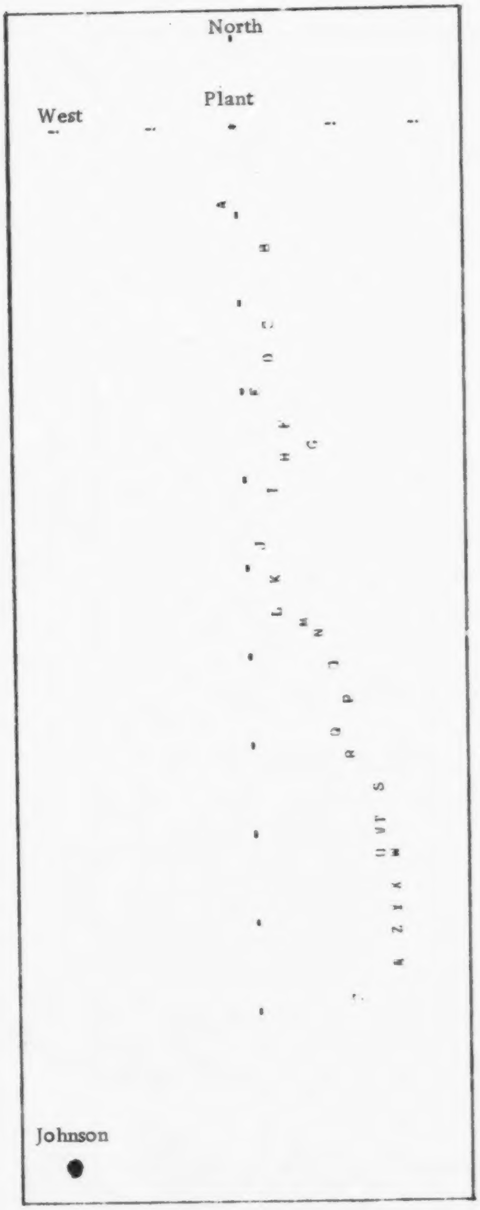

Figure 48. Calculated configuration of plume at 1050 EST, May 15, 1977.

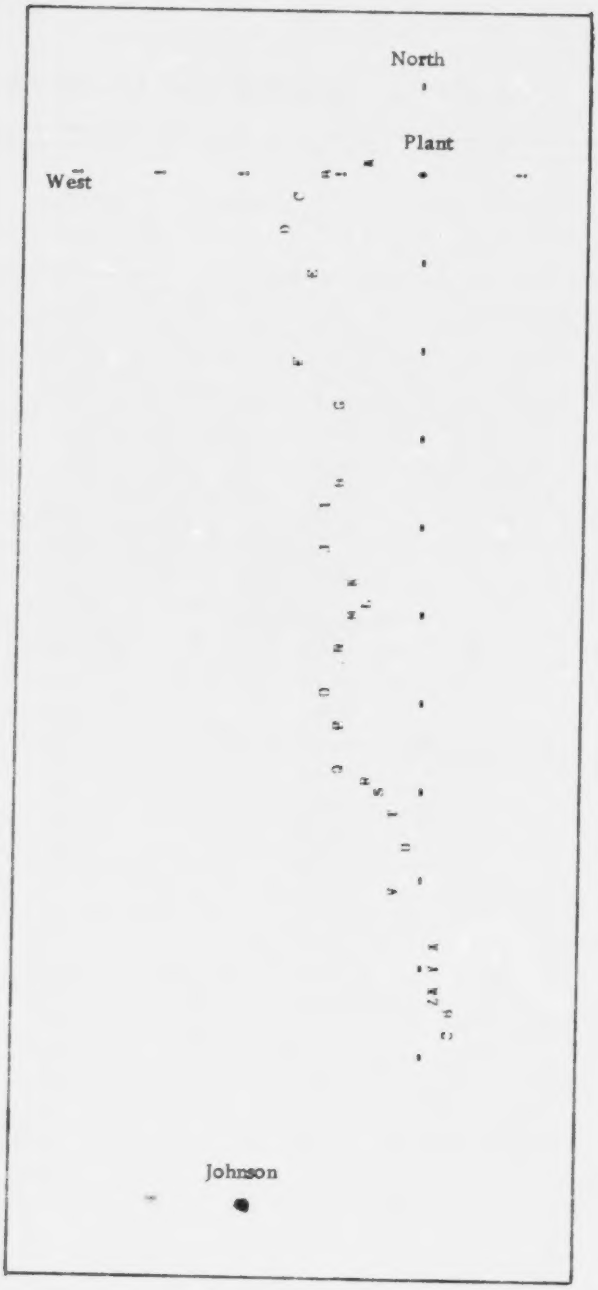
North
Plant
West
Johnson

Figure 49. Calculated configuration of plume at 1100 EST, May 15, 1977.

TABLE 47. 2-MINUTE SO_2 CONCENTRATIONS AT JOHNSON

Day	Time	Johnson SO_2 (ppb)
May, 15, 1977	1000	100
	1004	130
	1006	140
	1008	110
	1010	160
	1012	150
	1014	240
	1016	280
	1018	290
	1020	240
	1022	200
	1024	180
	1026	190
	1028	170
	1030	130
	1032	100
	1034	90
	1036	100
	1038	90
	1040	80
	1042	70
	1044	80
	1046	80
	1048	90
	1050	90
	1052	90
	1054	80
	1056	80
	1058	80
	1100	90

TABLE 48. CASE STUDY V DATA

		SO_2 Hourly Average/Peak (ppb)															
Date	Hour	Tower	Hockey	Kents	Munsey	Nashs	Plume Ht.* (m)	Hockey WS-30m (m/sec.)	Hockey WD-30m (deg.)	Hockey σ_A-30m (deg.)	Tower σ_E-30m (deg.)	Tower ΔT(30-0.5m) (°C)	Stability**	SO_2 Plant Emission (g/sec.)	Hockey WS-10m (m/sec.)	Hockey WD-10m (deg.)	Hockey σ_A-10m (deg.)
June 29	23	2/2	6/6	0/0	3/3	0/0	210	2.9	--	--	9.6	2.1	6	1128	0.1	308	47
	24	2/2	6/6	0/0	3/3	0/0	226	1.3	193	30	19.5	2.0	6	1092	0.5	172	27
June 30	1	2/2	6/6	0/0	3/3	0/0	243	1.8	237	15	20.7	1.6	6	1120	1.4	200	11
	2	2/2	6/6	0/0	3/3	0/0	269	2.2	246	10	14.4	1.3	6	1086	1.4	220	14
	3	2/2	6/6	0/0	3/3	0/0	284	1.4	259	30	4.4	0.8	6	1082	0.3	218	55
	4	2/2	107/1160	0/0	3/3	0/0	314	1.2	278	24	4.6	0.3	6	1098	0.3	290	53
	5	2/2	318/960	0/0	3/3	0/0	289	1.2	233	37	8.1	0.8	6	1088	0.2	192	62
	6	2/2	4/6	0/0	3/3	0/0	269	3.3	196	4	20.8	0.5	6	1086	1.5	167	7
	7	2/2	0/6	0/0	3/3	0/0	233	3.7	209	7	8.7	-0.1	5	1112	1.9	180	14
	8	4/12	0/6	0/0	3/3	0/0	259	3.0	200	10	20.8	-0.3	4	1218	1.4	170	11
	9	59/112	1/6	0/0	3/3	3/26	250	4.7	200	11	30.0	-0.1	6	1348	3.5	182	14
	10	68/92	5/6	0/5	7/13	11/26	532	5.0	207	14	17.2	-0.5	2	1406	4.2	192	20

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* Calculated from average heat flux of the 2 stacks.

** Based on bulk Richardson number classification; see text on page 190.

Figures 50 to 58 display the configuation and direction of the plume based on 2-minute scans of Hockey 30 m wind speeds and directions. When the plume configurations in those figures are compared to the corresponding 2-minute scans of SO_2 concentrations in Table 49, there appears to be a good correlation between plume position and SO_2 concentrations at Hockey, i.e., generally as the plume approached Hockey, SO_2 concentrations increased and as the plume retreated from Hockey, SO_2 concentrations decreased. It can be concluded from this analysis that the vector addition of 2-minute winds at Upper Hockey predicted the position of the plume reasonably well for this case study.

Using the Gaussian relationship,

$$x = \left(\frac{Q}{\pi \sigma_y \sigma_z u} \right) \exp \left[- \frac{1}{2} \left(\frac{H}{\sigma_z} \right)^2 \right]$$

where x = centerline concentration at ground

σ_y = horizontal dispersion coefficient

σ_z = vertical dispersion coefficient

H = effective stack height

Q = emission rate

for the calculated plume height of 314 m at the plant and for very stable conditions, the ground level concentration (x) at Hockey (only 17 m from the plume centerline in the vertical) was computed to be approximately 117×10^6 ppb using Pasquill-Gifford dispersion parameters and assuming the plume centerline was directly over Hockey. The peak concentration observed at Hockey was 1160 ppb. If this incident represented a direct hit by the plume at the Hockey site, then σ_y and σ_z, as determined by Pasquill-Gifford, are too small, thus resulting in an overestimation of the plume concentration. Other explanations for the discrepancy are that the horizontal position of the plume did not directly intersect the Hockey site, or that the plume rose to cross the ridge.

Case Study VI (0700-1000 EST, July 6, 1977)

During this case study elevated SO_2 hourly average concentrations were observed at Hockey and Munsey and slightly elevated concentrations were observed at Tower (see Table 50). The weather over southwest Virginia was synoptically influenced by a high pressure ridge extending from the Gulf of Mexico to western Pennsylvania. The stability classifications ranged from very stable to unstable as the vertical temperature difference became more negative through the morning. The available Hockey 30 m wind data showed the wind speeds to be light, the hourly average directions highly variable and the sigma azimuths relatively large. A pibal/T-sonde launched at 1005 EST showed the wind speeds in the lowest 500 m to be

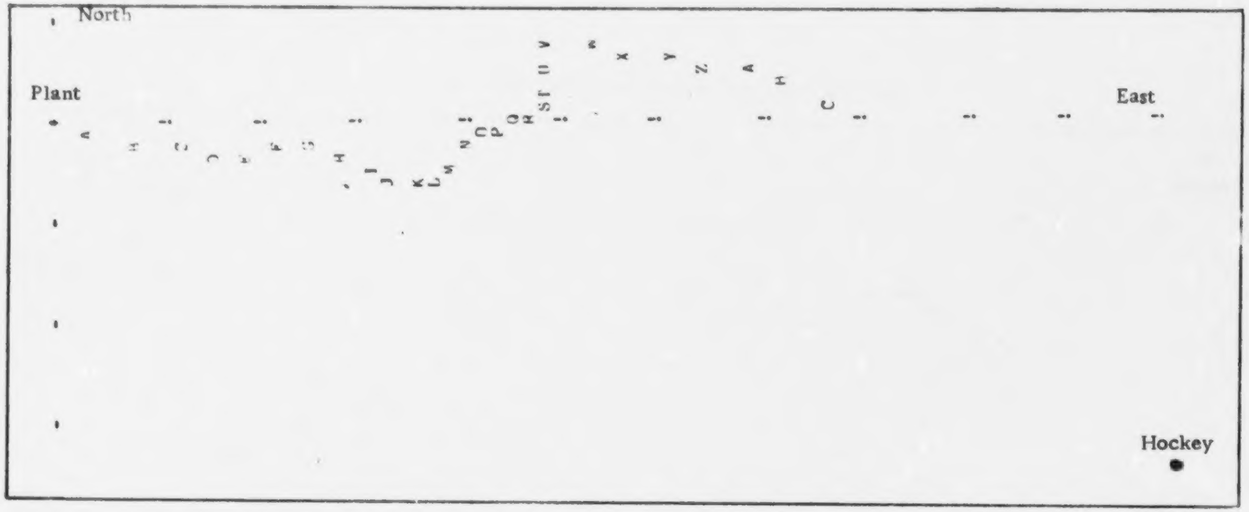


Figure 50. Configuration of plume at 0340 EST, June 30, 1977.

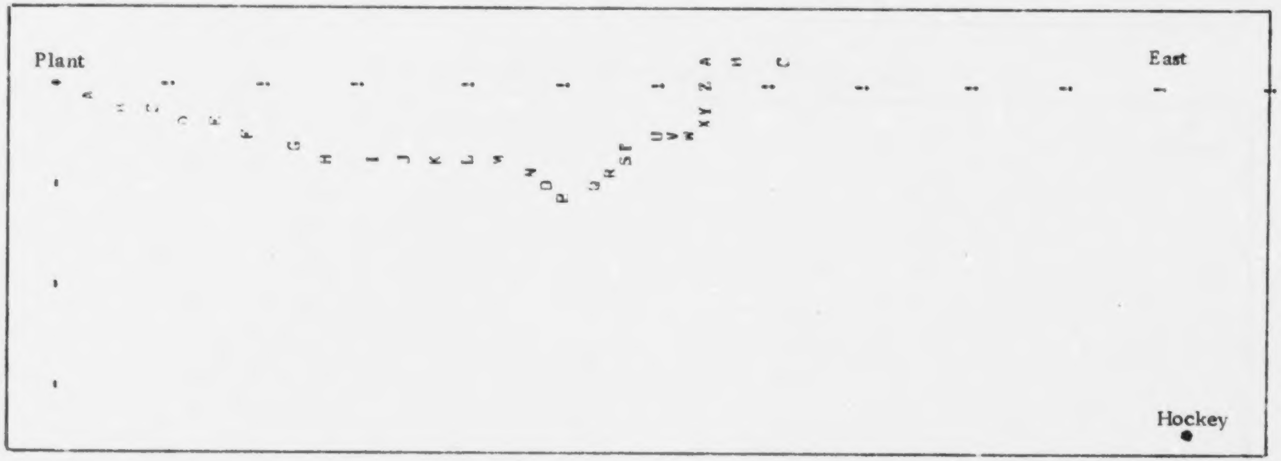


Figure 51. Configuration of plume at 0350 EST, June 30, 1977.

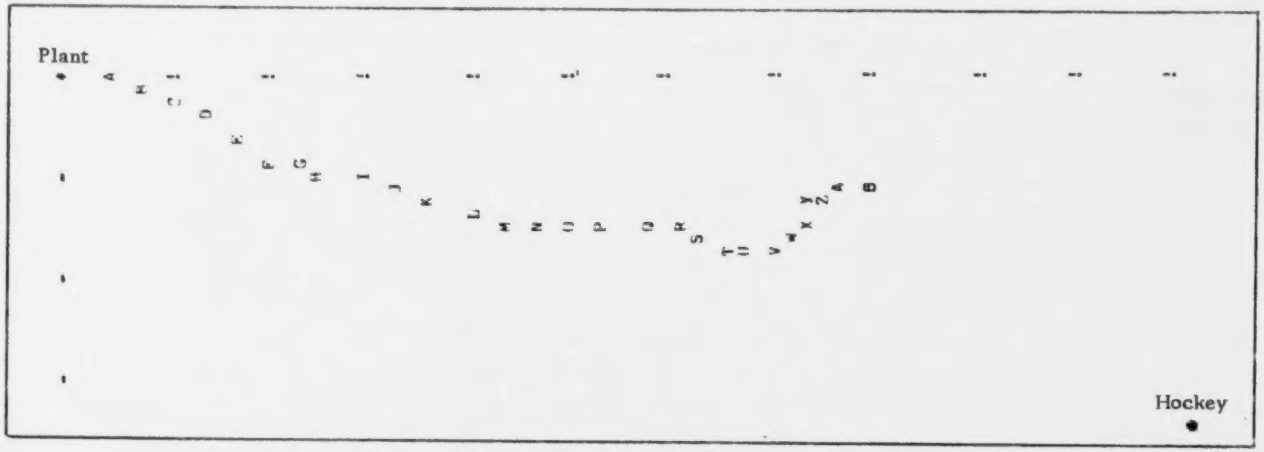


Figure 52. Configuration of plume at 0400 EST, June 30, 1977.

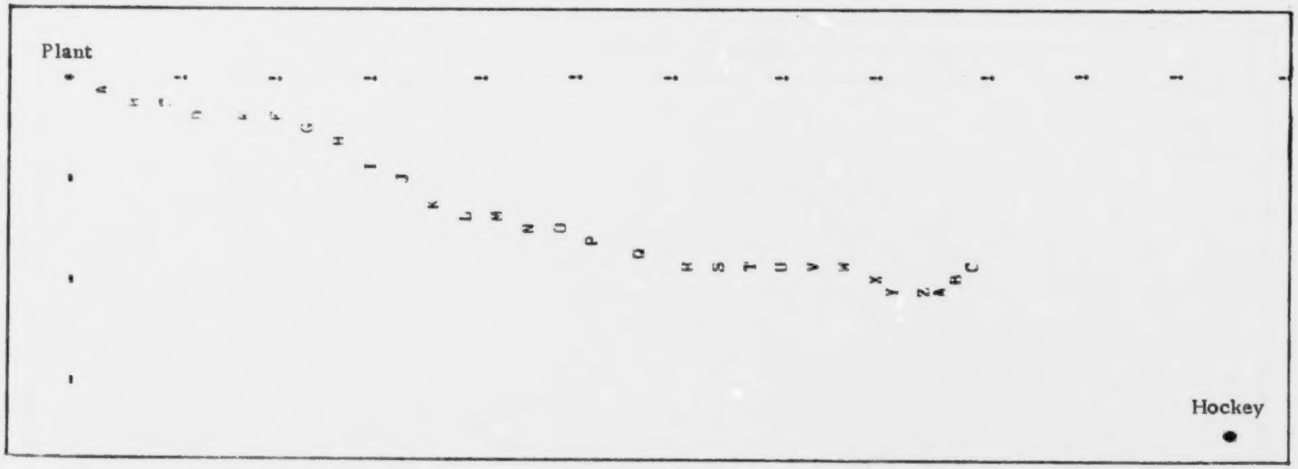


Figure 53. Configuration of plume at 0410 EST, June 30, 1977.

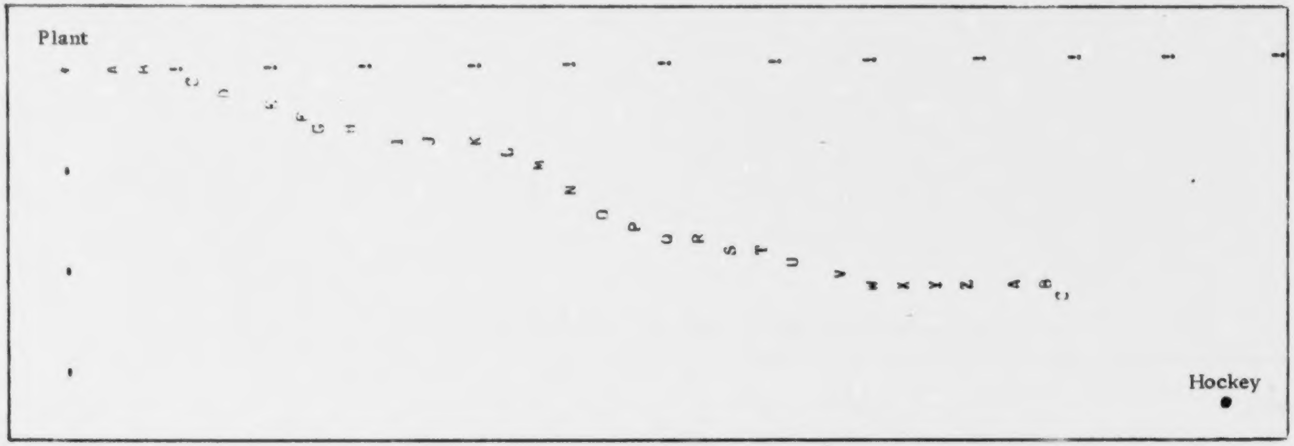


Figure 54. Configuration of plume at 0420 EST, June 30, 1977.

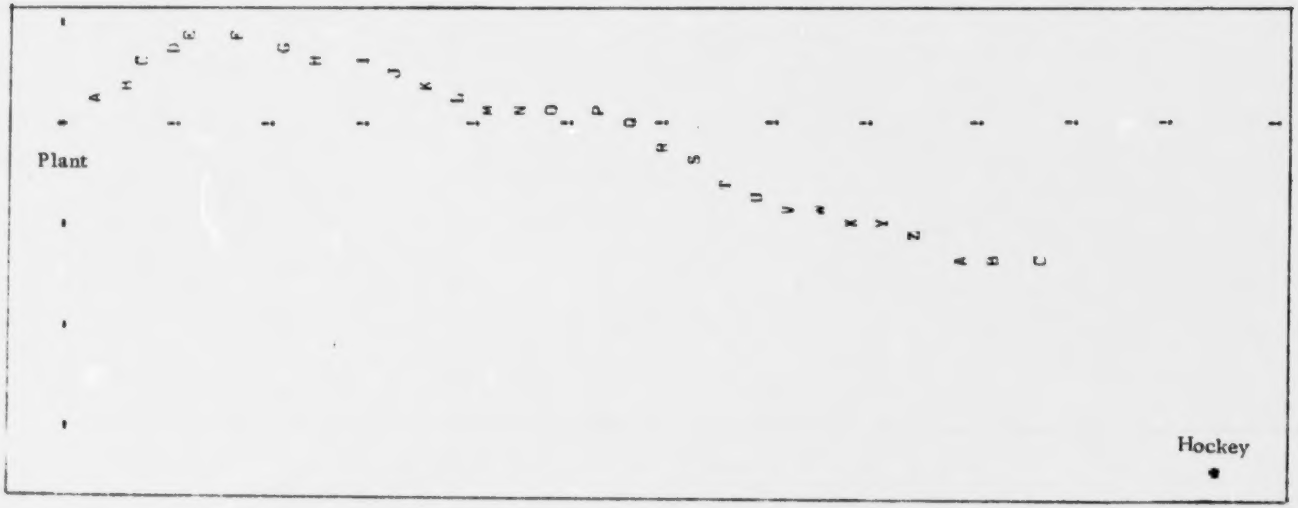


Figure 55. Configuration of plume at 0430 EST, June 30, 1977.

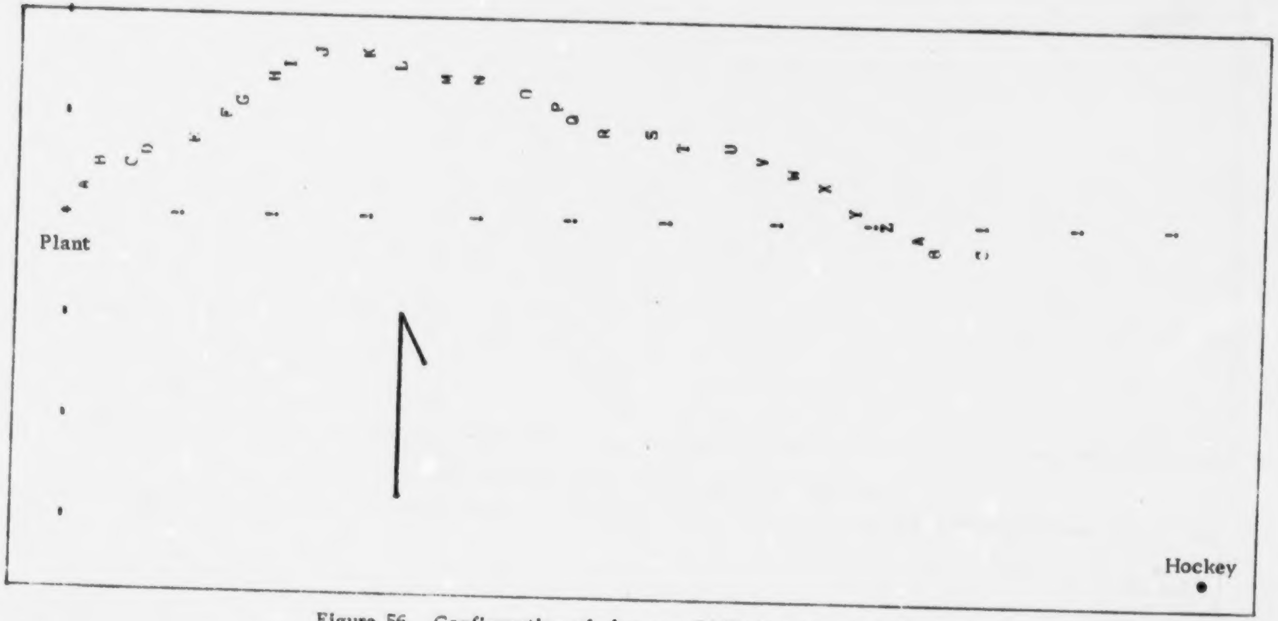


Figure 56. Configuration of plume at 0440 EST, June 30, 1977.

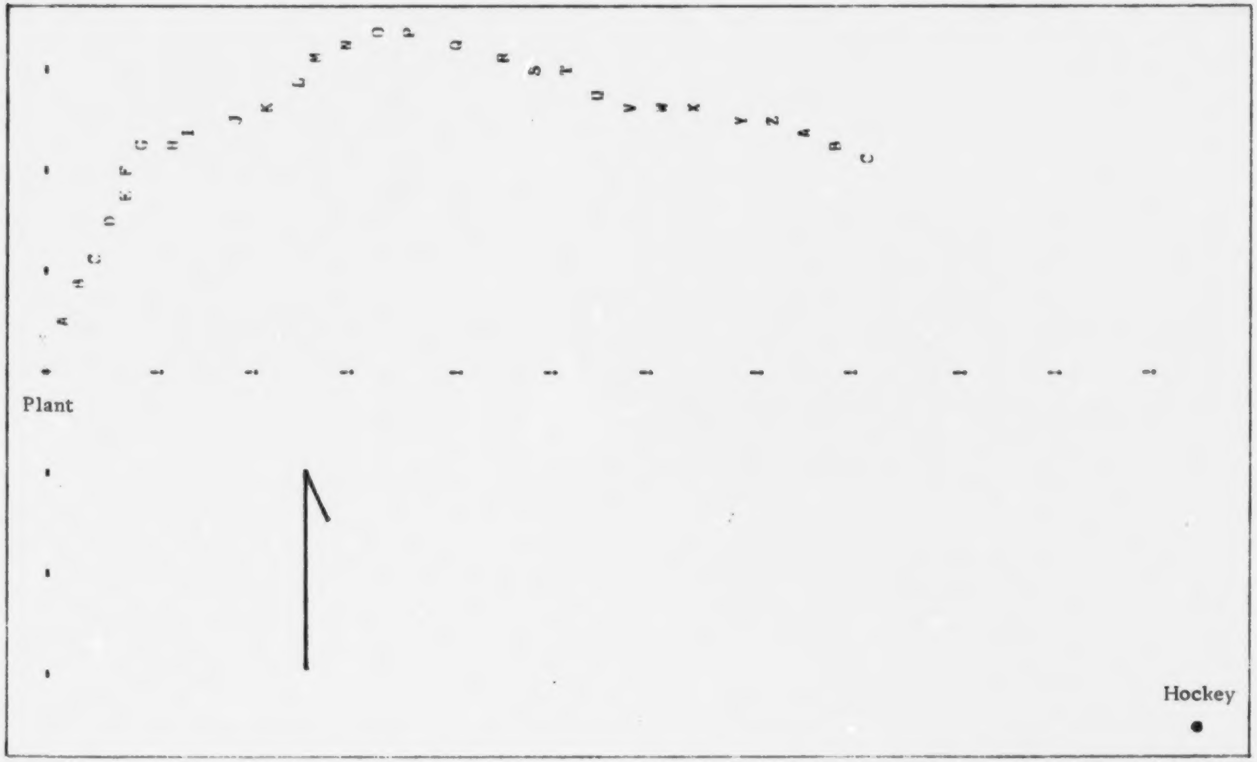


Figure 57. Configuration of plume at 0450 EST, June 30, 1977.

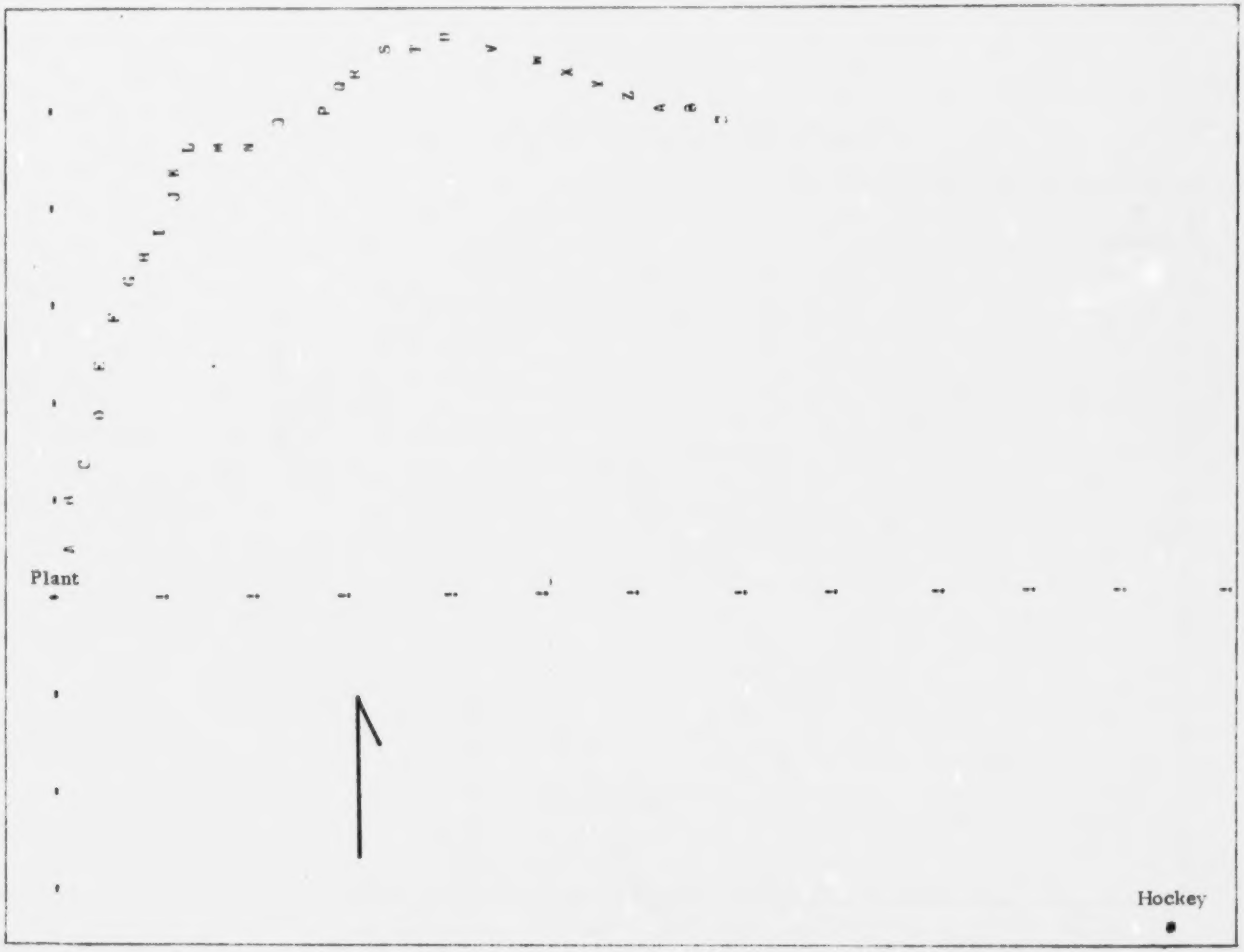


Figure 58. Configuration of plume at 0500 EST, June 30, 1977.

TABLE 49. 2-MINUTE SO_2 CONCENTRATIONS AT HOCKEY

Day	Time	Hockey SO_2 (ppb)
581	0338	10
	0340	10
	0342	10
	0344	10
	0346	170
	0348	180
	0350	50
	0352	20
	0354	10
	0356	1090
	0358	1160
	0400	960
	0406	870
	0408	870
	0410	770
	0412	730
	0414	380
	0416	290
	0418	180
	0420	420
	0422	570
	0424	370
	0426	220
	0428	270
	0430	210
	0432	190
	0434	280
	0436	290
	0438	390
	0440	220
	0442	120
	0444	70
	0446	50
	0448	50
	0450	40
	0452	30
	0454	20
	0456	20
	0458	10
	0500	10

TABLE 50. CASE STUDY VI DATA

		SO_2 Hourly Average/Peak (ppb)					Plume Ht.* (m)	Hockey WS-30m (m/sec.)	Hockey WD-30m (deg.)	Hockey σ_A-30m (deg.)	Hockey WS-10m (m/sec.)	Hockey WD-10m (deg.)	Hockey σ_A-10m (deg.)	Mumsey WS-10m (m/sec.)	Mumsey WD-10m (deg.)	Mumsey σ_A-10m (deg.)	Tower σ_E-30m (deg.)	Tower ΔT(30-, 5m) (°C)	Stability**	SO_2 Plant Emission (g/sec.)
Date	Hour	Tower	Hockey	Keats	Mumsey	Hasle														
July 6	2	3/3	6/6	1/11	17/30	0/0	343	1.9	222	14	1.3	185	15	0	76	95	4.0	0.5	6	859
	3	3/3	6/6	21/50	13/30	0/0	322	1.9	260	18	0.6	202	29	0	128	90	12.5	0.4	6	864
	4	3/3	5/6	15/47	11/30	0/0	321	1.8	242	28	0.7	183	18	0.1	43	89	22.5	0.4	6	863
	5	3/3	6/6	38/68	13/41	0/0	311	1.2	241	34	1.0	181	34	0.1	169	71	21.5	0.1	6	863
	6	3/3	5/6	21/42	13/41	0/0	300	1.5	259	27	1.0	204	26	0.1	140	25	20.2	0.1	6	862
	7	45/93	33/111	24/52	76/237	0/0	318	0.9	266	37	0.3	212	43	0.1	143	77	26.3	0	6	923
	8	71/83	148/313	20/57	182/236	0/0	358	0.4	319	78	0.1	180	99	0.2	351	55	20.0	-0.2	6	1,072
	9	46/53	25/63	10/45	178/247	0/0	305	1.8	76	16	0.8	4	33	0.9	350	29	15.3	-0.4	2	1,245
	10	32/43	6/17	1/25	18/162	0/0	327	2.6			0.6	2	24	1.4	6	24	16.5	-1.4	1	1,343
	11	22/21	6/6	0/0	7/9	0/0	406	3.3			1.2	357	29	1.2	29	54	15.0	-0.8	2	1,392
	12	17/23	5/6	0/0	9/9	0/0	412	3.1			1.2	353	31	1.3	339	50	21.9	-0.6	2	1,397
	13	13/13	5/6	0/0	9/9	0/0	328	2.1			0.4	316	54	0.3	302	98	14.8	-0.5	2	1,408
	14	13/13	6/17	0/0	9/9	0/0	324	2.2			0.3	311	69	0.6	33	74	22.7	-0.8	1	763
	15	13/13	7/17	0/0	10/20	0/0	336	1.9	278	40	0.4	266	55	0.4	258	76	13.0	-0.9	2	776

* Calculated from average heat flux of the 2 stacks.

** Based on bulk Richardson number classification; see text on page 130.

light and directions backing from 95° at 100 m to 353° at 500 m (Figures 59 and 60). As shown in Figure 61, the temperature profile is adiabatic to 500 m. Since the plume height is calculated to be 327 m at 1000 EST, the fumigation should be complete as is confirmed by the SO_2 measurements at all stations.

THis case study is another example of prolonged plume fumigation. In this case the height of the inversion above plant base had exceeded the height of all stations. A possible remnant of the inversion between 340 and 400 m in the 1005 EST T-sonde suggests the inversion extended to at least 400 m. Nash's did not observe elevated concentrations although this site was below both Hockey and Kent's. In order to understand the low concentrations at Nash's, the plume transport wind regime must be determined for the case study period. However, the wind regime is not entirely clear since light wind speeds and variable wind directions were reported at all stations. A more detailed analysis has not been performed.

A pibal/T-sonde released at 1202 EST (Figures 62, 63 and 64) indicated the atmosphere had a lapse rate that was approximately adiabatic to a height of at least 900 m above plant base.

Case Study VII (0800-1700 EST, July 24, 1977)

This case study included elevated SO_2 concentrations at Tower with simultaneous helicopter cross sections (see Table 51). The synoptic weather pattern was under the influence of a high pressure system off the Virginia coast. The first helicopter cross-section was performed between 0837 and 0856 at a distance of 3.1 km from the plant (Figures 65 and 66).

Figure 65 shows the major terrain features of the area surrounding the plant. The location of the cross-section is illustrated with a dotted line. Figure 66 presents the cross-section as it would have appeared if viewing it from the plant. Each point represents an SO_2 concentration (ppb) observed during a helicopter traverse. Only those points greater than 50 ppb and the adjacent points were plotted. Figure 67 presents the cross-section as viewed from a radial plane eminating from the plant. Each slash in the vertical represents a helicopter traverse elevation. The associated number is the total mass (g) of SO_2 in a theoretical homogenous volume in which the dimensions were determined by the length of the traverses, the vertical spacing of the traverses, and a width of one meter (Figure 68).

The center of mass of the plume was calcualted to be at a bearing of 34° and an elevation of 363 m above plant base. It appears that the plume was dispersing into a stable layer thus inhibiting the vertical spread of the plume. The Tower site, which was located in the same plane as the cross-section and approximately 600 m laterally from the center of mass, had an hourly average SO_2 concentration of 31 ppb and a peak of 85 ppb for the hour ending 0900 EST. A pibal without T-sonde released at 0847 showed the wind directions to be backing in the lowest

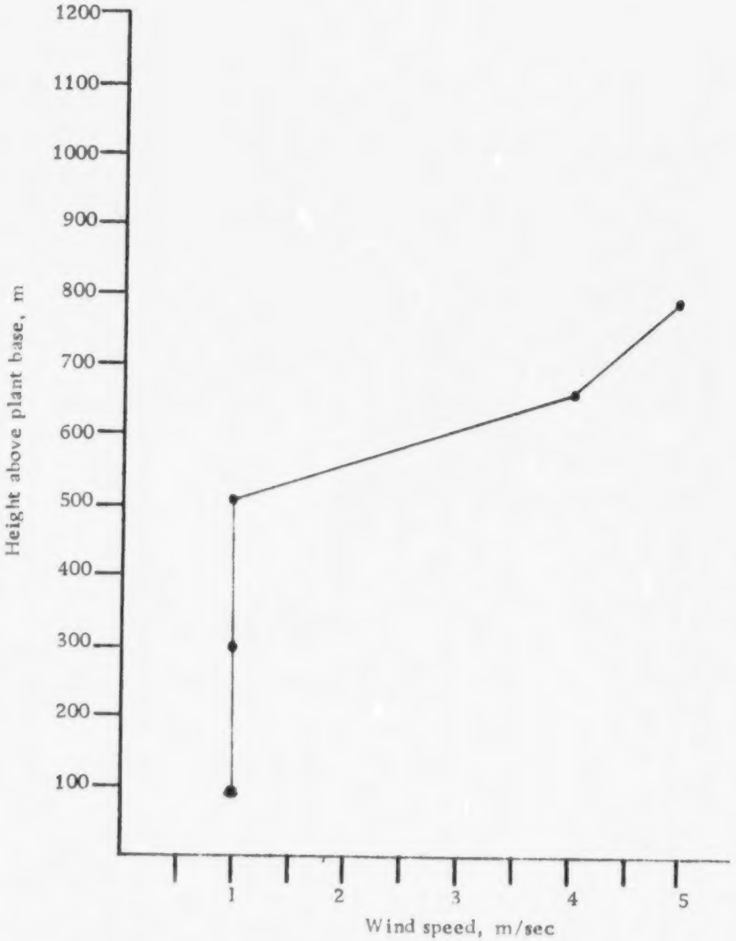


Figure 59. Wind speed (m/s) profile at 1005 EST, July 6, 1977 at the plant.

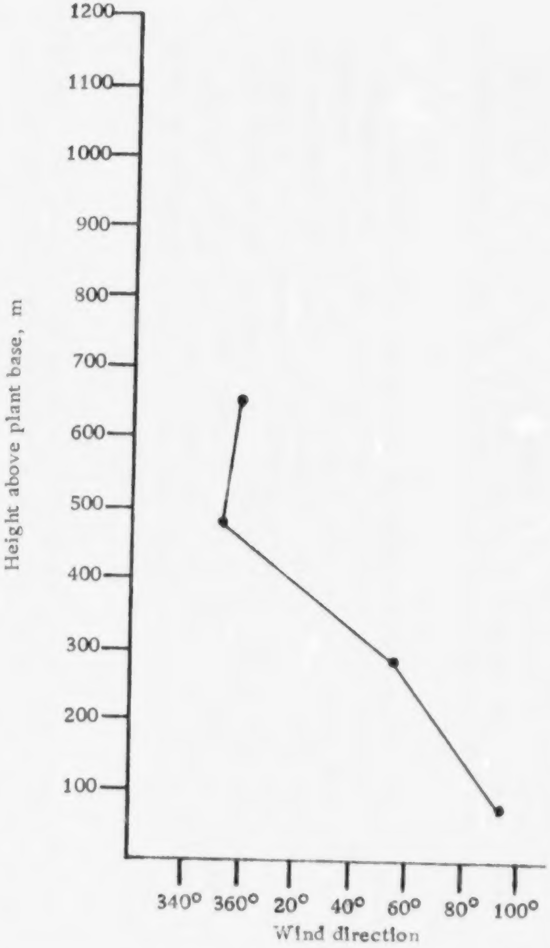


Figure 60. Wind direction profile at 1005 EST, July 6, 1977.

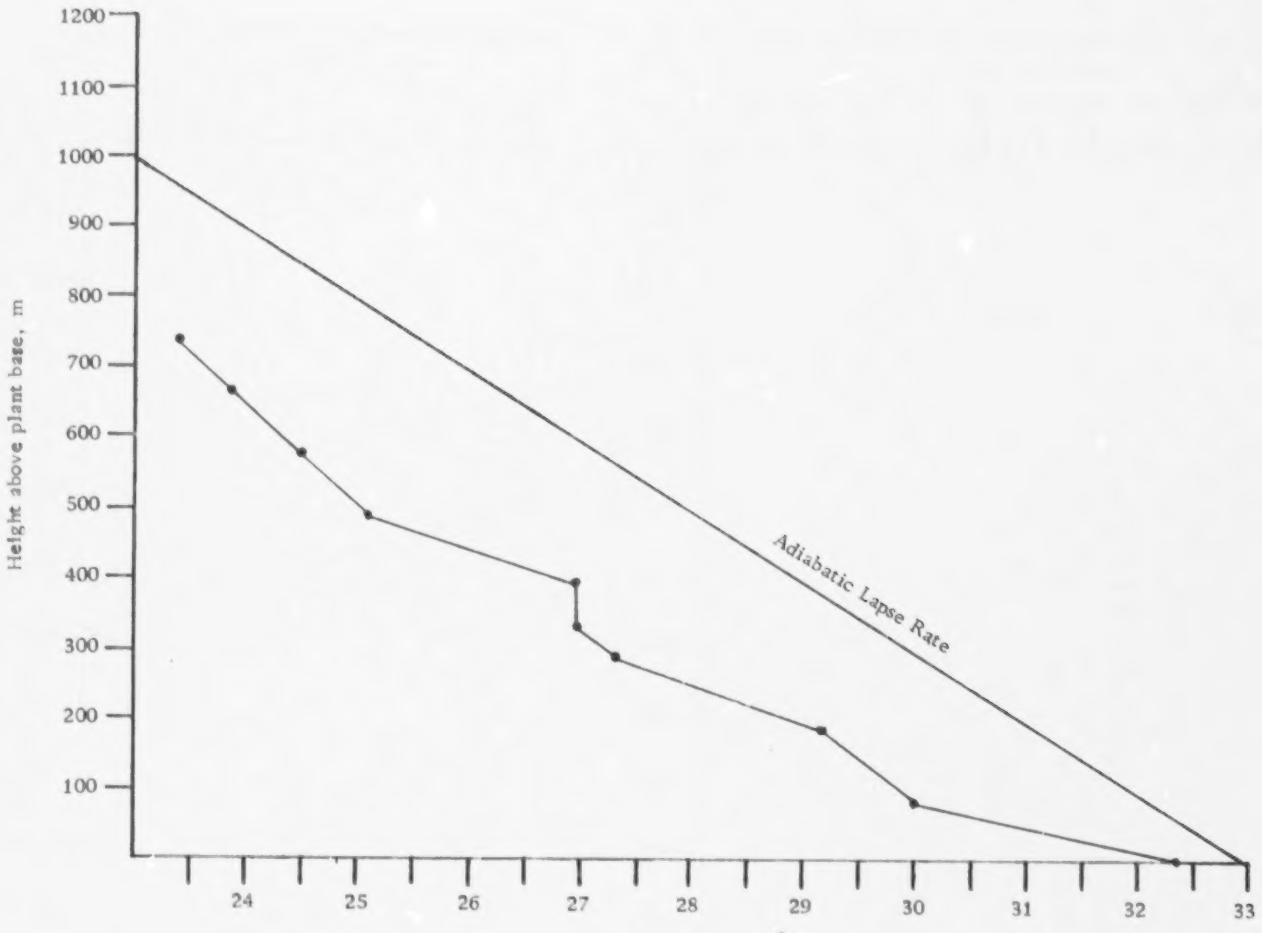


Figure 61. Temperature (°C) profile at 1005 EST, July 6, 1977.

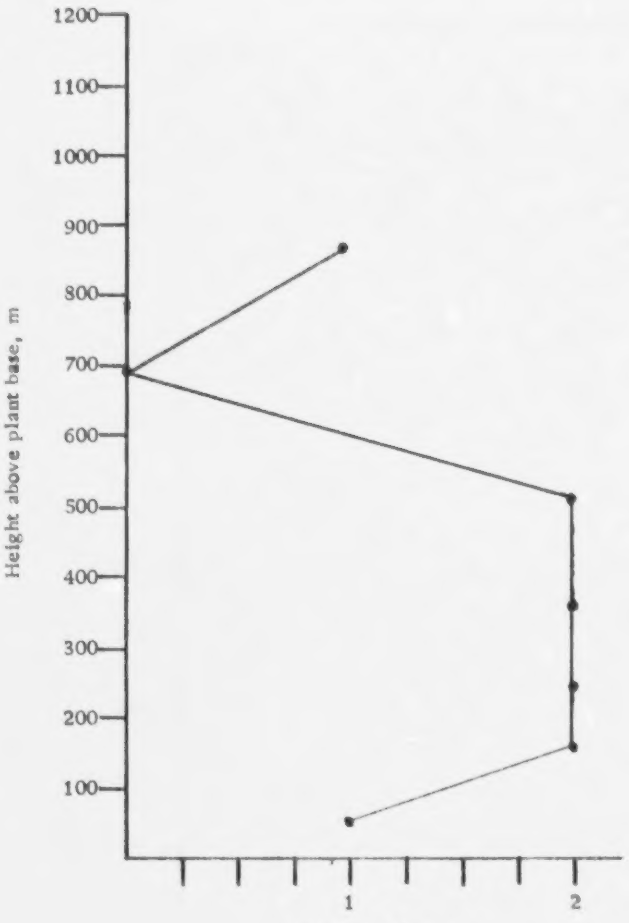


Figure 62. Wind speed (m/s) profile at 1202 EST, July 6, 1977.

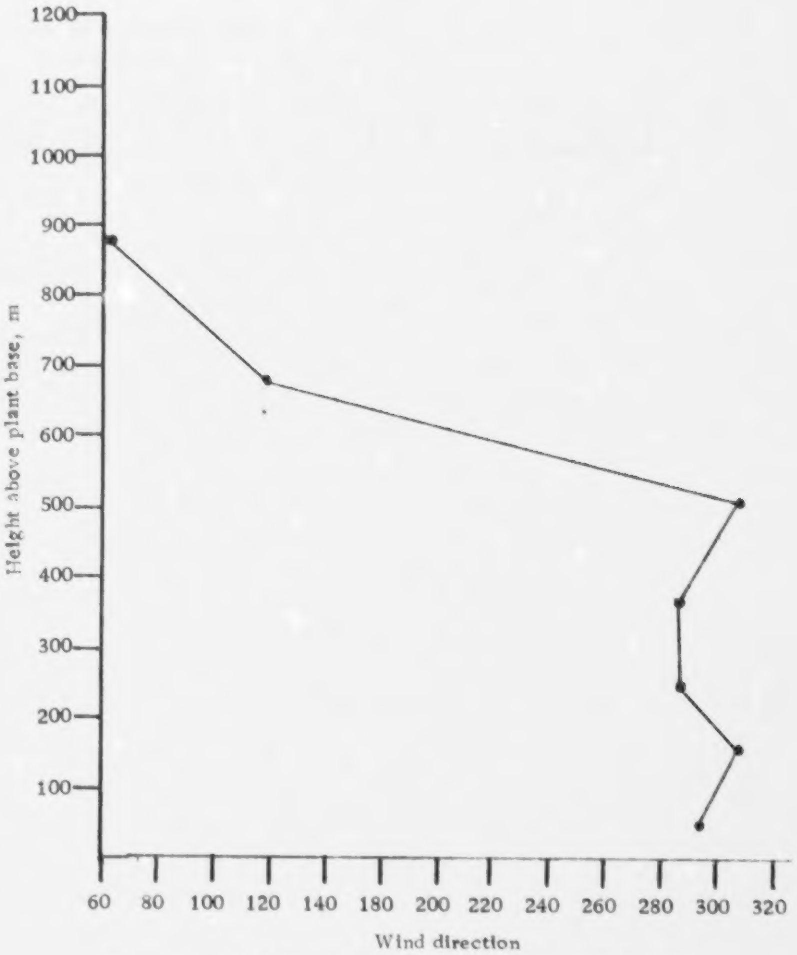


Figure 63. Wind direction profile at 1202 EST, July 6, 1977.

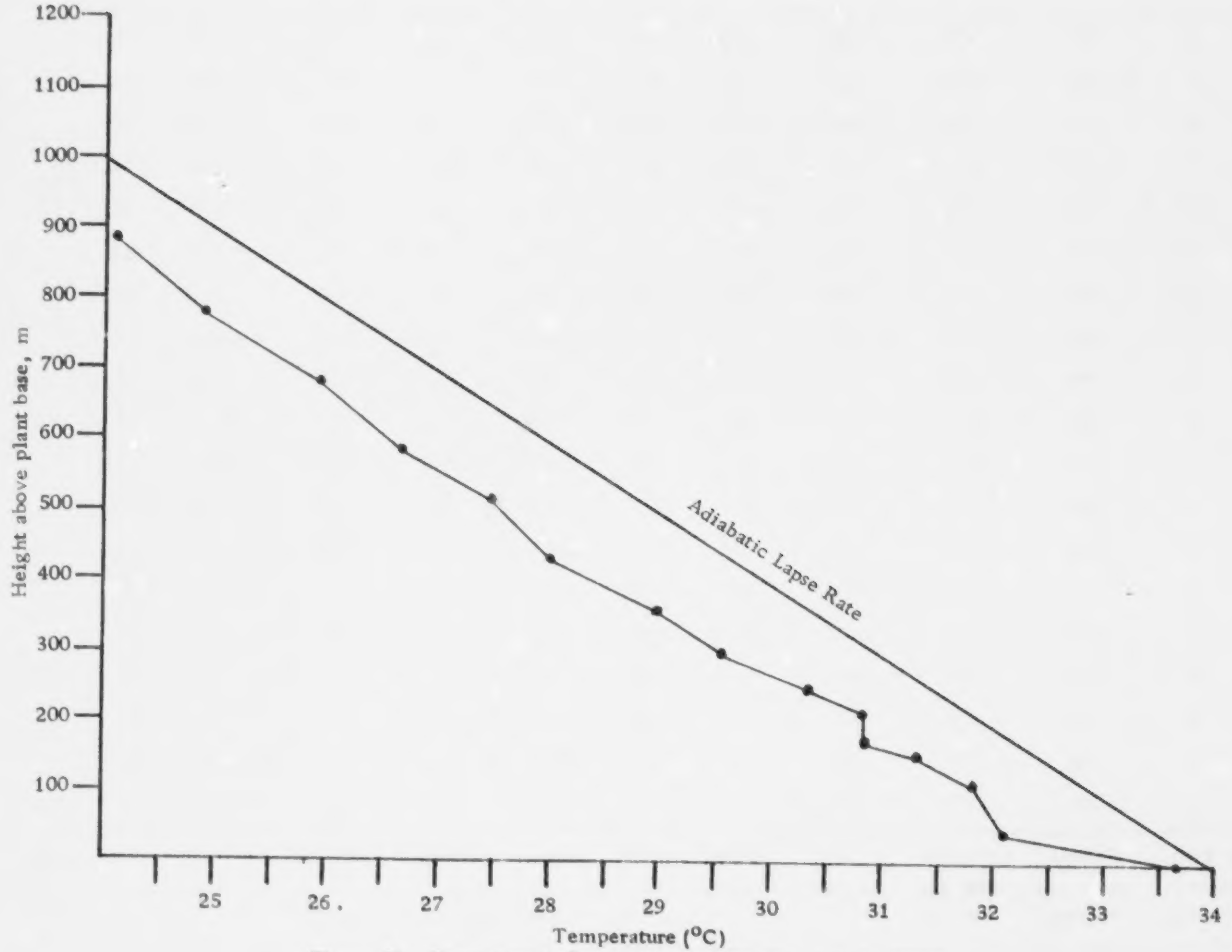


Figure 64. **Temperature (°C) profile at 1202 EST, July 6, 1977.**

TABLE 51. CASE STUDY VII DATA

		SO_2 Hourly Average/Peak (ppb)										
Date	Hour	Tower	Hockey	Kents	Johnson	Munsey	Nashs	Plume Ht.* (m)	Hockey WS-30m (m/sec.)	Hockey WD-30m (deg.)	Hockey σ_A-30m (deg.)	SO_2 Plant Emission (g/sec.)
July 24	4	4/4	0/6	0/0	11/19	0/7	0/0	166	4.0	207	7	574
	5	4/4	1/6	0/0	10/19	0/7	0/0	166	4.4	203	7	573
	6	4/4	0/6	0/0	10/19	0/7	0/0	167	4.4	207	7	569
	7	4/4	1/6	0/0	12/19	0/7	0/0	178	4.3	212	5	569
	8	31/135	0/6	0/0	10/19	0/7	0/0	224	4.3	204	7	573
	9	31/85	0/6	0/0	10/19	4/7	0/0	302	4.5	214	6	583
	10	38/175	0/6	0/0	9/19	0/7	0/0	422	4.8	222	10	587
	11	73/165	0/6	0/0	6/19	0/7	0/0	495	6.6	232	14	638
	12	21/85	0/6	0/0	6/6	0/0	0/0	515	6.8	231	10	797
	13	15/34	1/6	0/0	6/6	0/0	0/0	275	6.0	230	18	883
	14	0/4	0/6	0/0	6/6	0/0	0/0	220	4.7	246	24	808
	15	68/286	2/6	0/0	6/6	0/0	0/0	214	6.9	238	17	914
	16	4/14	5/6	0/0	6/6	2/7	0/0	426	3.5	254	18	953
	17	2/4	3/6	0/0	6/6	0/0	0/3	420	2.3	273	28	928
	18	12/44	0/6	0/0	6/6	0/0	1/15	427	2.2	241	19	972
	19	7/24	0/6	0/0	6/6	0/0	0/0	360	2.3	241	11	956
	20	0/4	0/6	0/0	6/6	0/0	0/0	284	3.1	237	10	968
	21	2/14	0/0	0/0	6/19	0/0	0/0	275	3.2	232	9	992
	22	0/4	0/6	0/0	8/19	0/0	0/0	254	2.9	210	14	973

* Calculated from average heat flux of the 2 stacks.

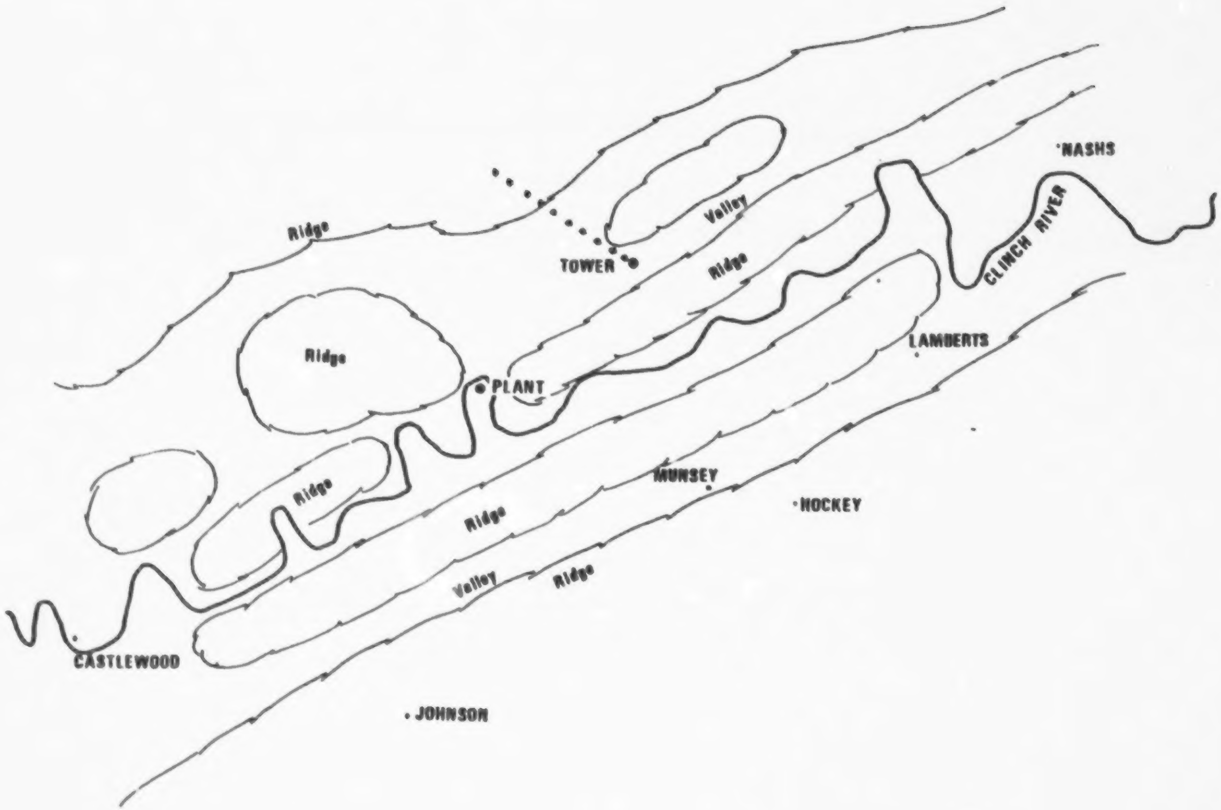

Ridge
TOWER
Valley
Ridge
NASHS
CLINCH RIVER
Ridge
PLANT
LAMBERTS
Ridge
MUNSEY
HOCKEY
Ridge
Valley
Ridge
CASTLEWOOD
JOHNSON

Figure 65. Location of helicopter cross-section - July 24, 1977 - 0837-0856 EST.

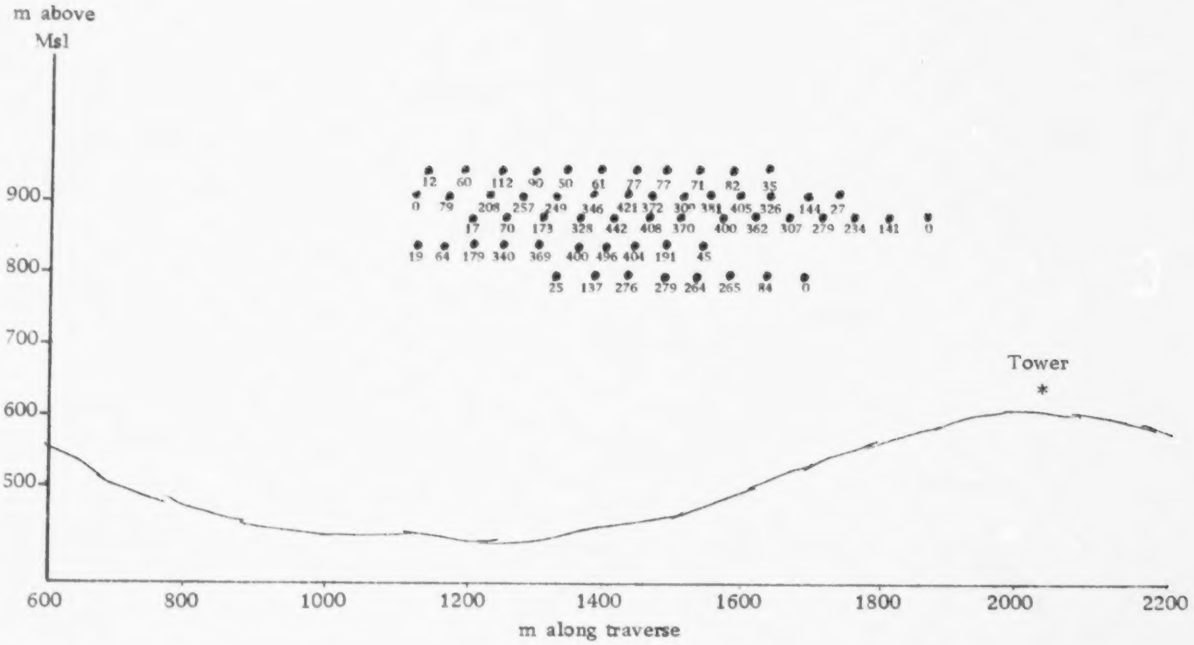


Figure 66. Helicopter cross-section - July 24, 1977 - 0837-0856 EST.

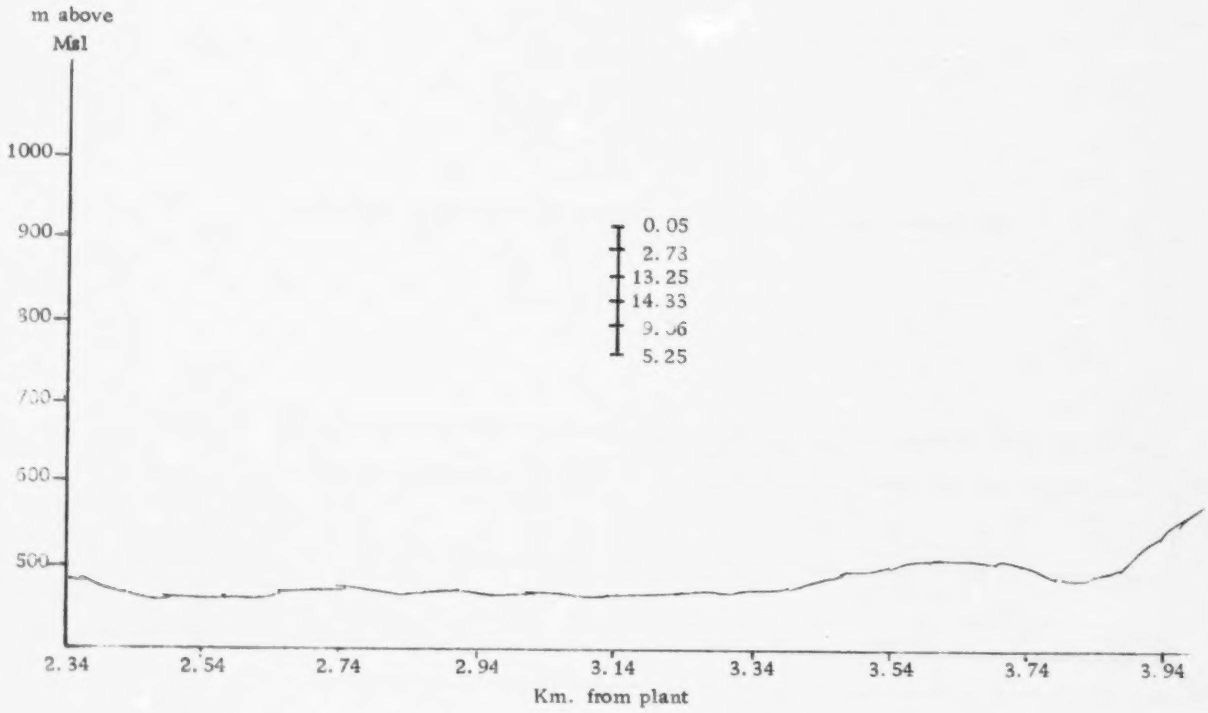


Figure 67. Longitudinal view of helicopter cross-section - July 24, 1977, 0837-0856 EST.

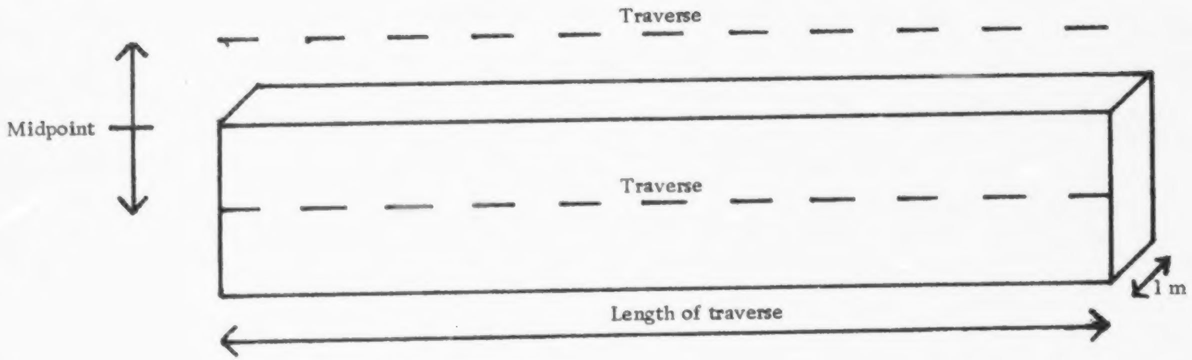

Traverse
Midpoint
Traverse
1 m
Length of traverse

Figure 68. Theoretical volume of air sampled during helicopter traverse .

500 m and veering aloft; wind directions at plume height were observed to be 215° (Figures 69 and 70).

Another helicopter cross-section was completed at 0947 at a distance of 6.2 km from the plant. The center of mass for this cross-section was calculated to be at a bearing of 34° and an elevation of 442 m above plant base. A pibal without T-sonde released at 0943 showed wind directions to be backing in the lowest 400 m and veering above; wind direction at plume height was observed to be 224° (Figure 71). Figure 73 shows a longitudinal view of the two cross-sections ending at 0856 and 0947 and their relationship to the terrain. It appears from this figure that the plume centerline rose as it crossed Buffalo Mountain. This is substantiated by the higher elevation of the center of mass computed for the latter cross-section.

Figures 74 to 80 pertain to three separate helicopter cross-sections done at the same location for different times during this case study. These three cross-sections show the plume to have greater spread in the horizontal than the cross-section completed at 0856. Apparently, later in the day, the plume shifted positions frequently between helicopter traverses. This assumption is supported by the increases in sigma azimuths observed at the 30 m Hockey level over the duration of this case study period. With the exception of 1600 and 1700 EST, Hockey 30 m wind directions appear to have correlated well with the horizontal position of the plume center of mass as determined by the helicopter cross-sections. Perhaps the reason for poor correlation between estimated plume bearing and center of mass bearing during 1600 and 1700 EST involves the nature of the cross-sections (i.e., the plume shifted positions between traverses, the full vertical extent of the plume was not sampled, etc.). These conclusions are in disagreement with the analysis of the helicopter cross-sections conducted by Thompson (1979) in the EPA wind tunnel study at Research Triangle Park. In that paper Thompson used several helicopter traverses to support the wind tunnel findings that with wind directions of 238° the plume was being deflected to the north by a ridge immediately to the northeast of the plant. However, Thompson based his conclusions on the helicopter data that had not been corrected for instrument response time and lag time due to the plumbing of the ambient air intake system. Also, Thompson examined only several traverses and not the whole cross-section. As illustrated in Figure 75 the location of the plume varied significantly between traverses.

Table 52 provides the observed bearing of the center of mass and the corresponding estimate of the bearing of the plume as determined by the 30 m wind directions at Hockey.

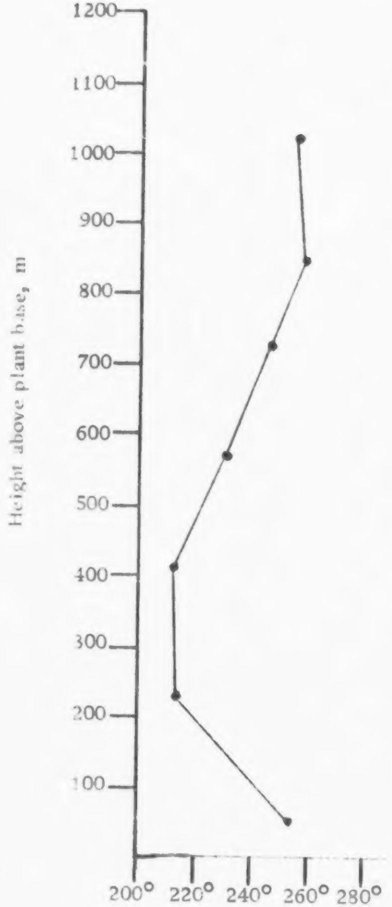


Figure 69. Wind direction profile at 0847 EST, July 24, 1977 at the plant.

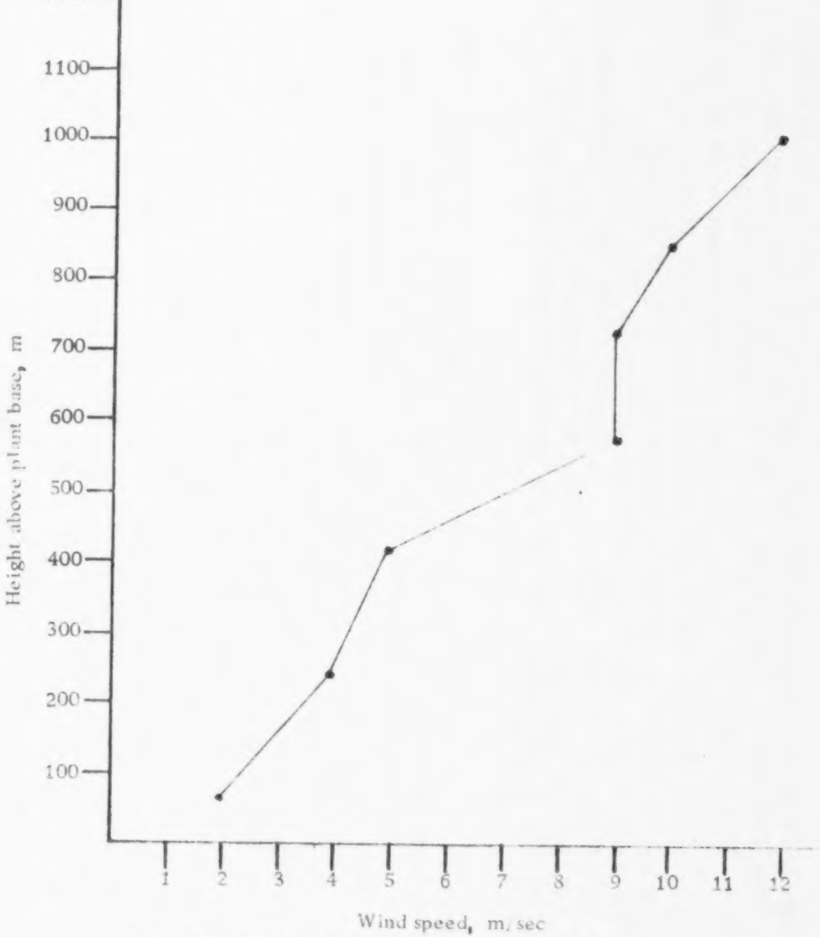


Figure 70. Wind speed (w/s) profile at 0847 EST, July 24, 1977.

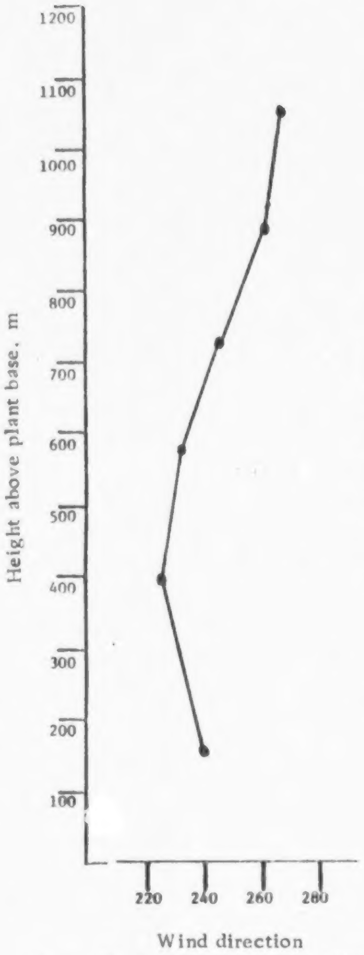


Figure 71. Wind direction at 0943 EST, July 24, 1977.

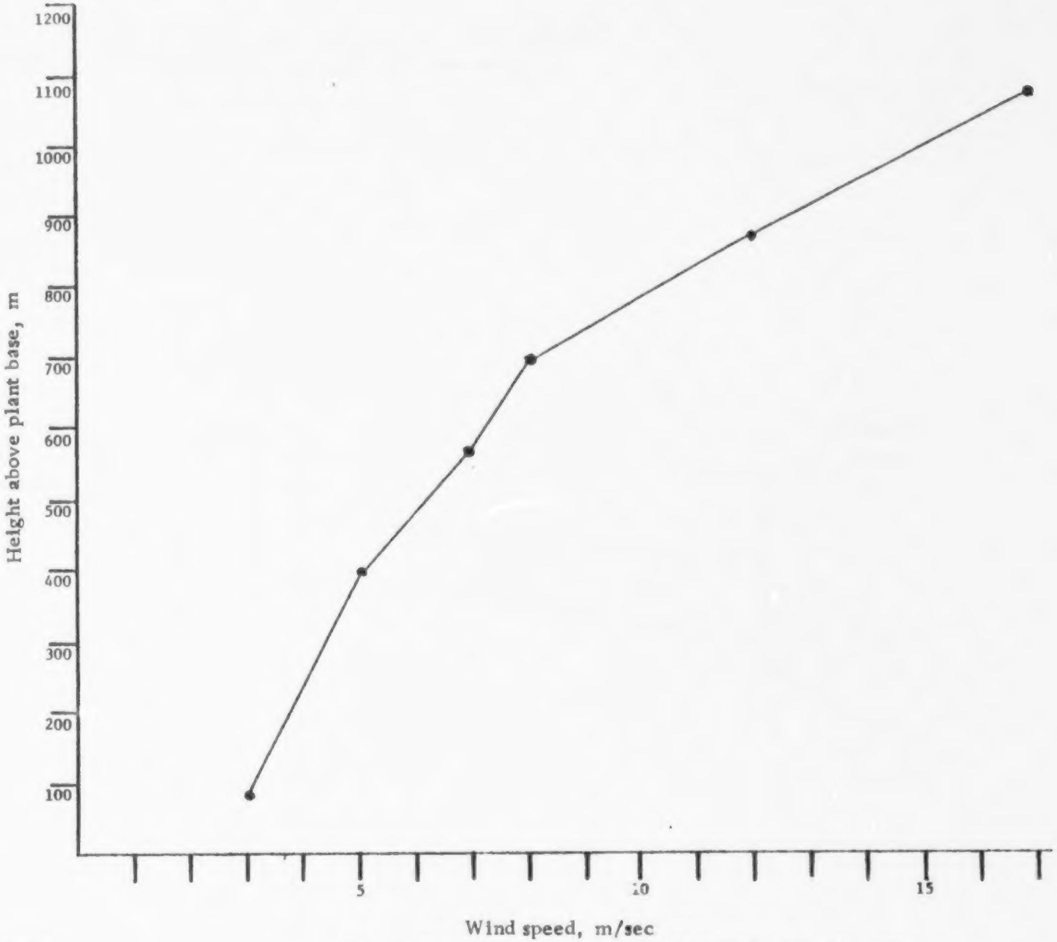


Figure 72. Wind speed (m/s) at 0943 EST, July 24, 1977.

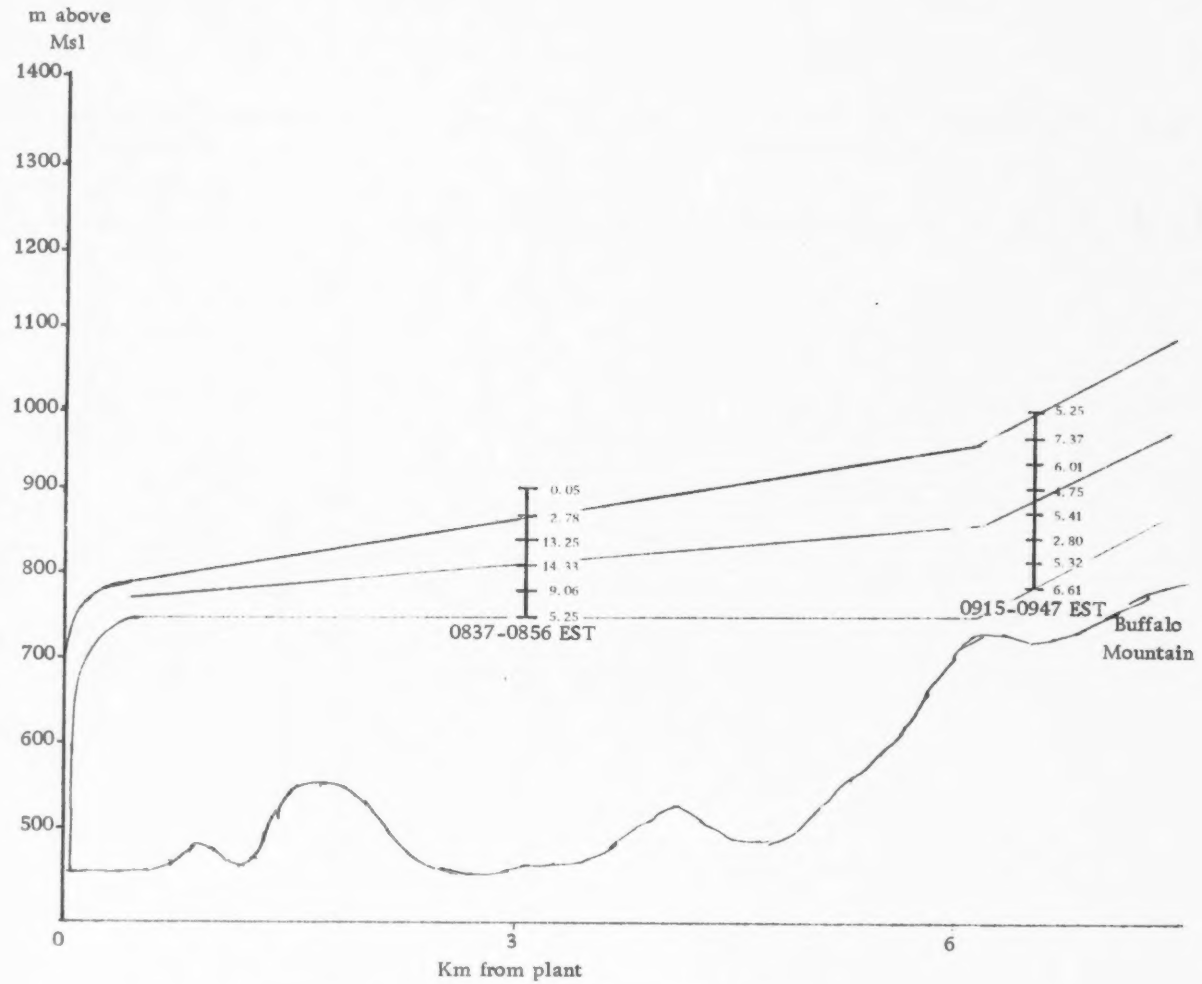


Figure 73. Longitudinal view of helicopter cross-sections - July 24, 1977 - 0837-0856 EST and 0915-0947 EST.

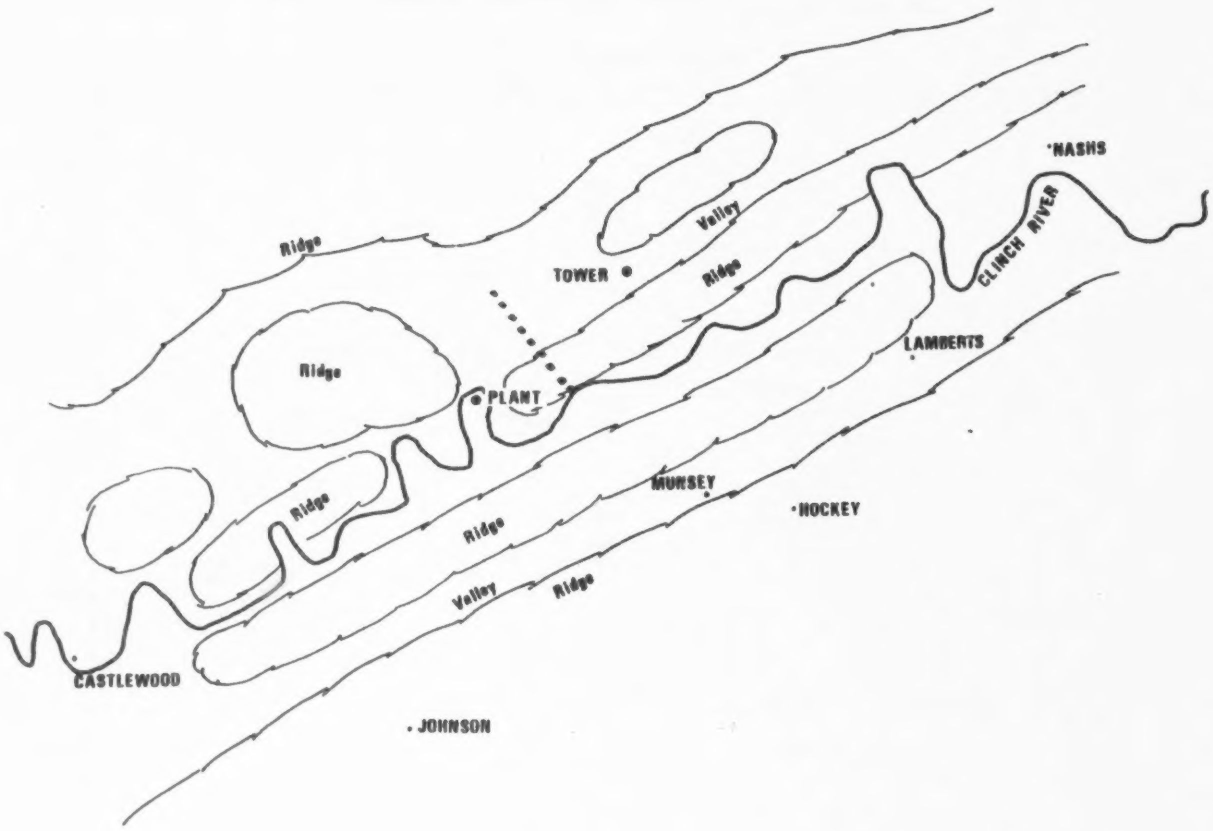

Ridge
Valley
TOWER
Ridge
'NASHS
CLINCH RIVER
Ridge
PLANT
LAMBERTS
Ridge
MUNSEY
•HOCKEY
Ridge
Valley
Ridge
CASTLEWOOD
• JOHNSON

Figure 74. Location of helicopter cross sections - July 24, 1977 - 1202-1304, 1306-1353, 1607-1621 EST.

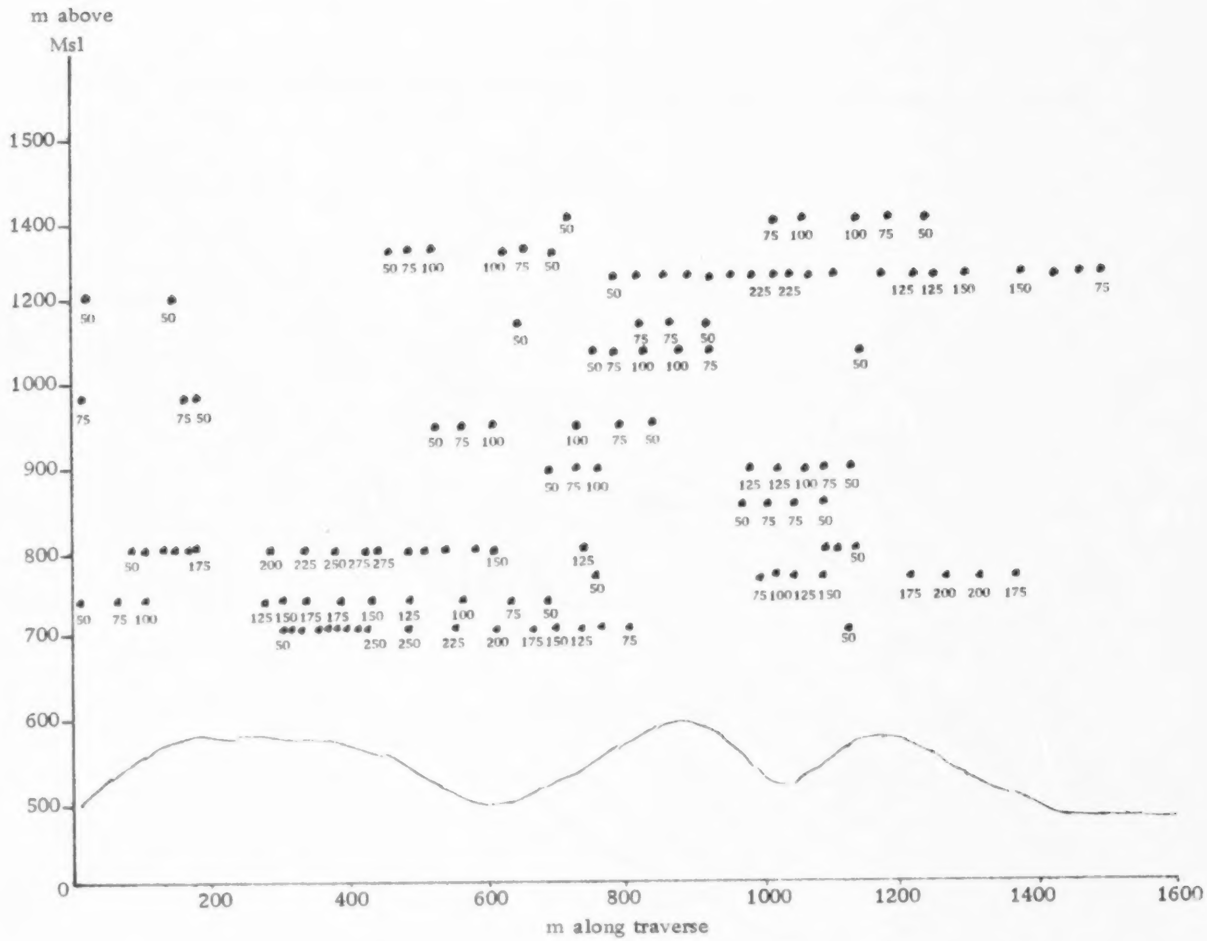


Figure 75. Helicopter cross section - July 24, 1977 - 1202-1304 EST.

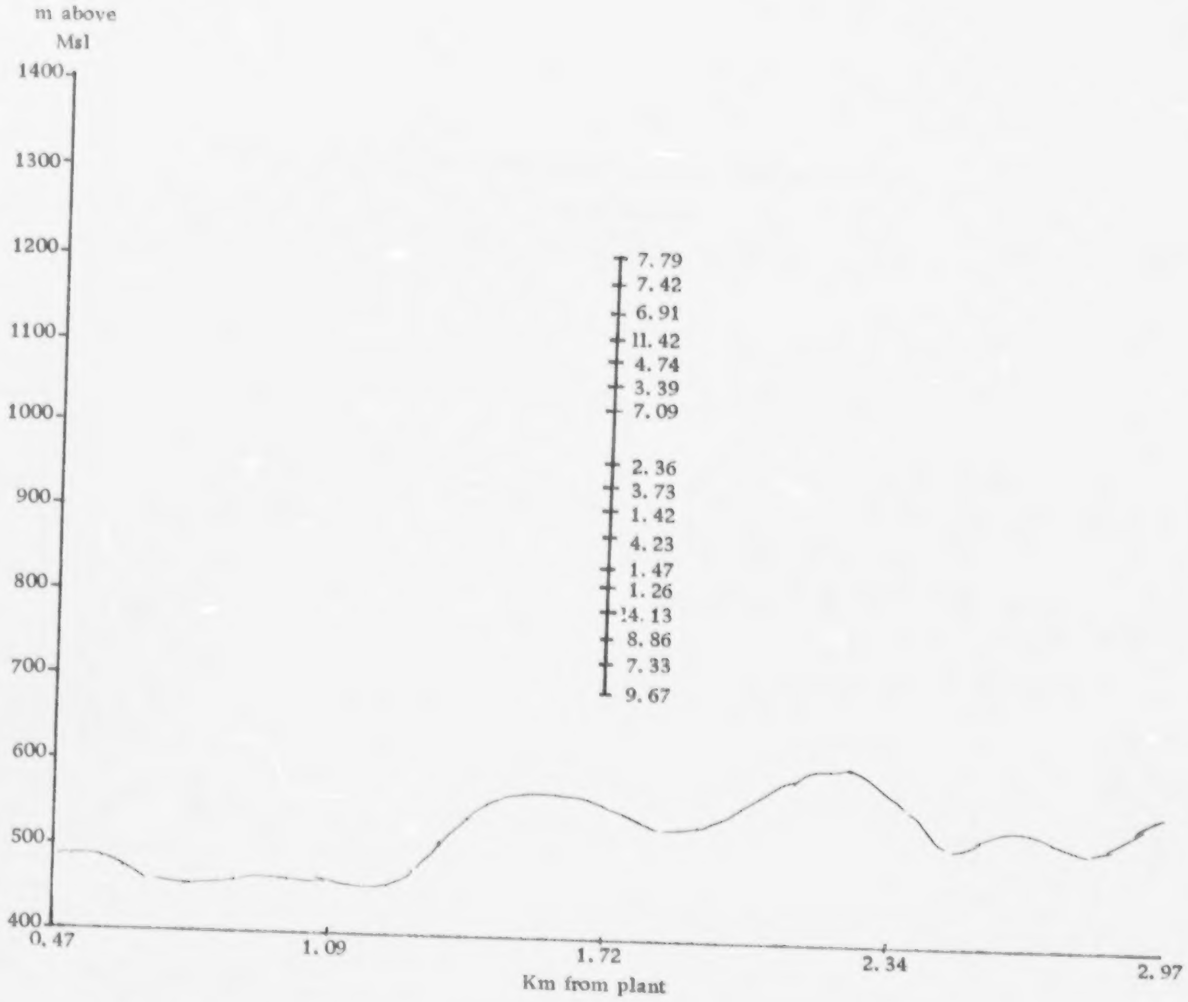


Figure 76. **Longitudinal view of helicopter cross-section - July 24, 1977, 1202-1304 EST.**

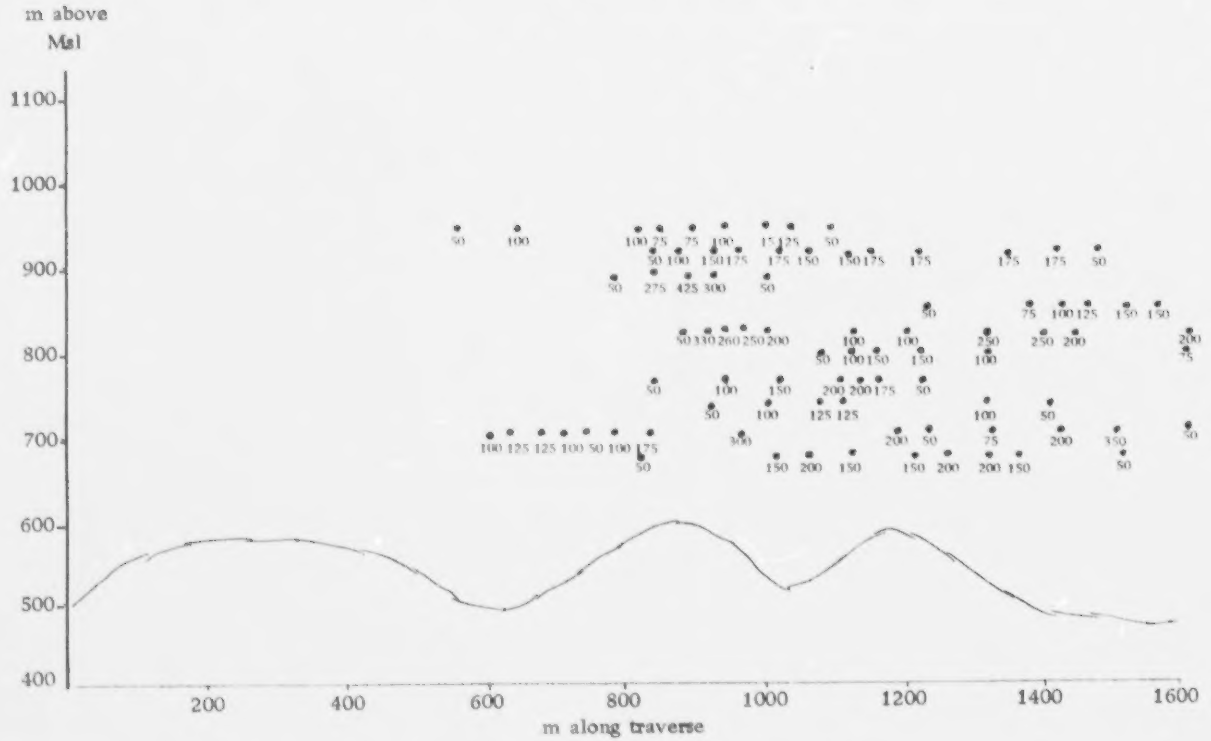


Figure 77. Helicopter cross-section - July 24, 1977, 1306-1353 EST.

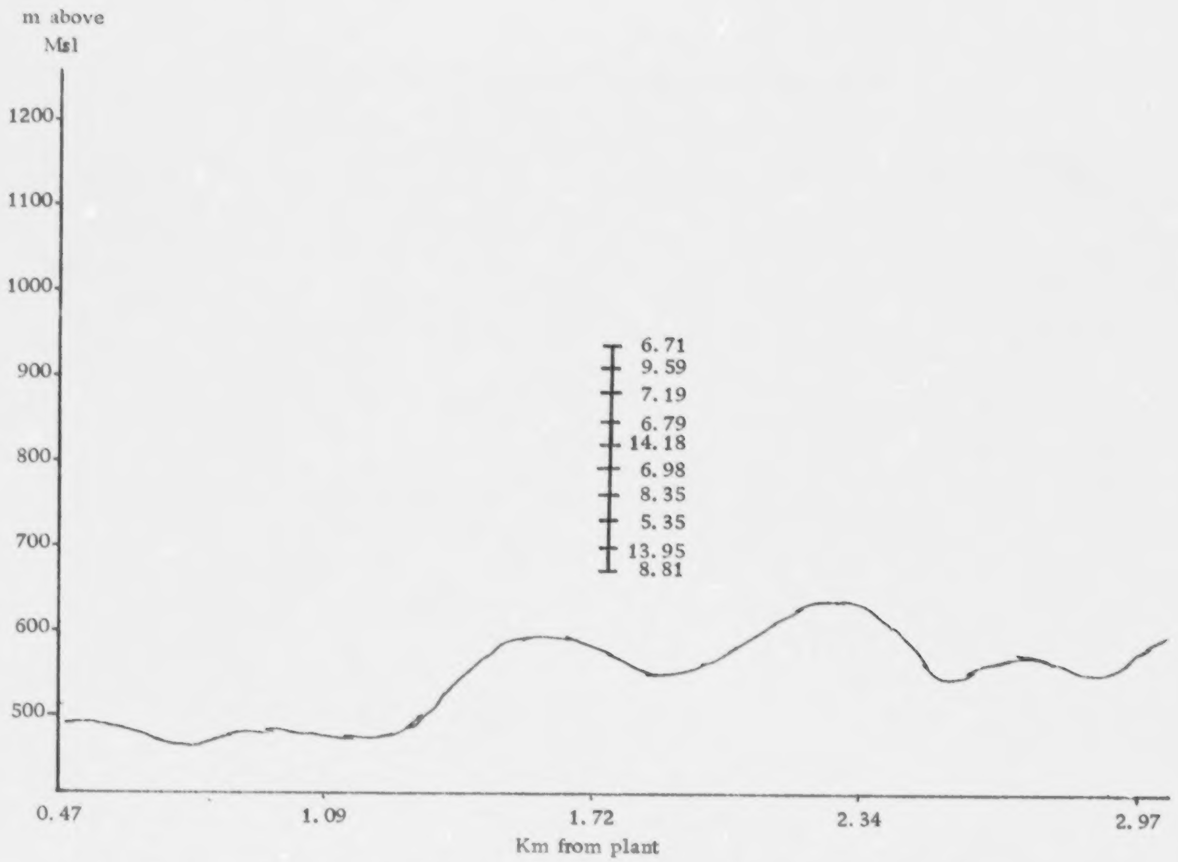


Figure 78. Longitudinal view of helicopter cross-section - July 24, 1977, 1306-1353 EST.

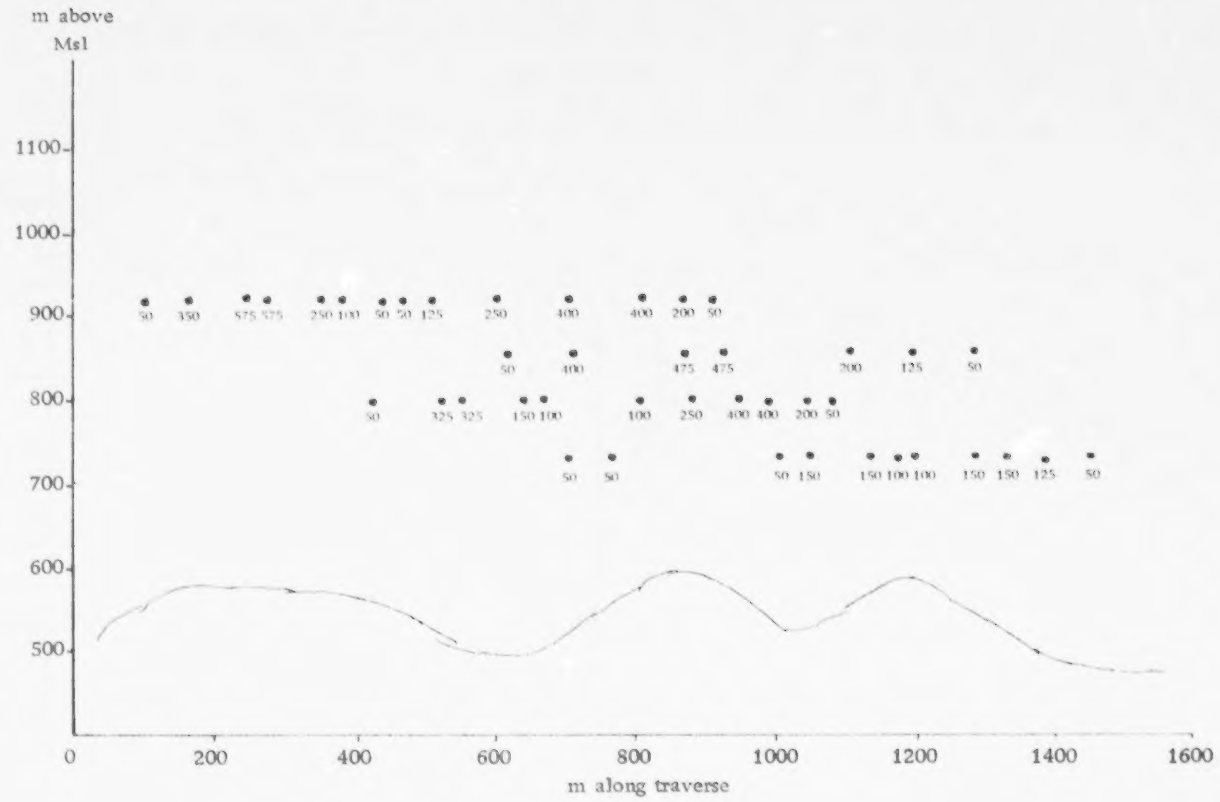


Figure 79. Helicopter cross-section - July 24, 2977, 1607-1621 EST

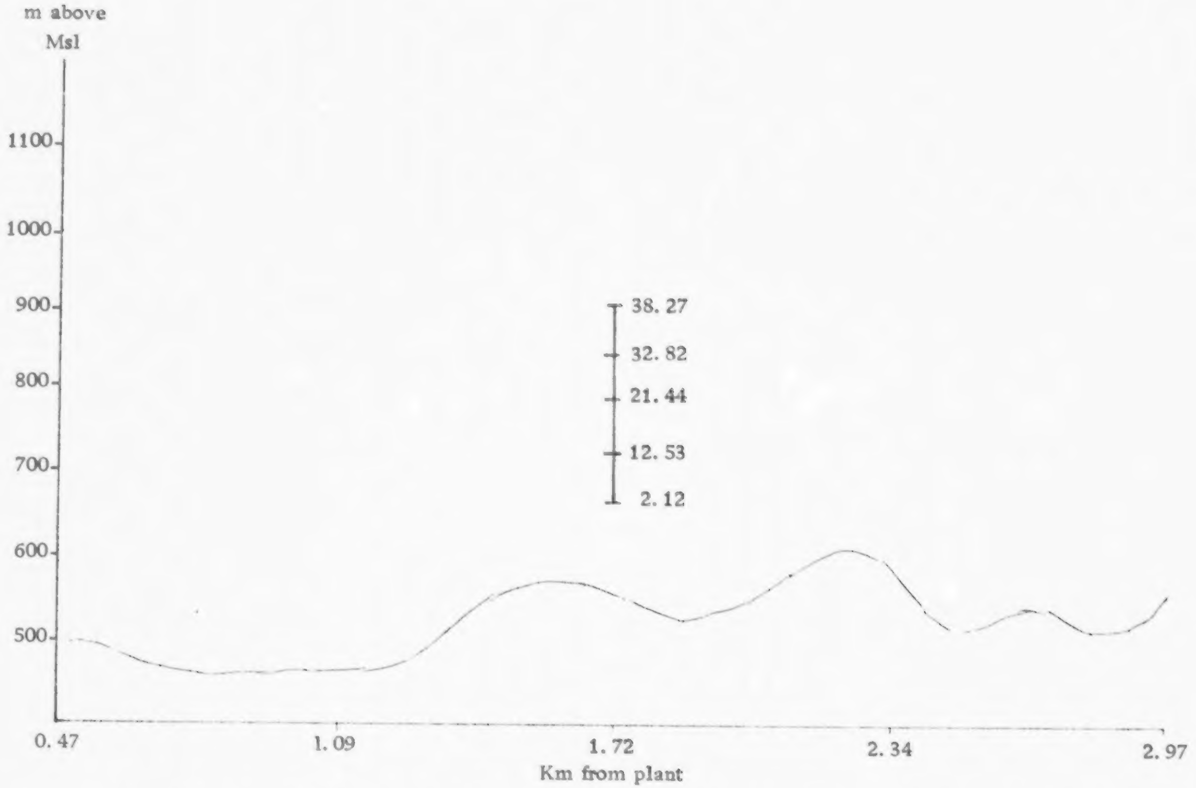


Figure 80. Longitudinal view of helicopter cross section - July 24, 1977, 1607-1621 EST.

TABLE 52. ESTIMATED PLUME BEARING AND BEARING OF CENTER OF MASS

Day	Time (EST)	Estimated Plume Bearing from Hockey Winds	Actual Center of Mass Bearing
July 24	0900	34°	34°
	1000	42°	35°
	1100	52°	54°
	1300	50°	54°
	1400	66°	58°
	1500	58°	54°
	1600	74°	54°
	1700	93°	54°

Case Study VIII (1100 - 1700 EST, July 26, 1977)

This case study contains moderately elevated concentrations at Johnson with simultaneous helicopter cross-sections of the plume (see Table 53). Over the case study period hourly averages showed wind speeds ranging from 3.2 to 5.0 m/s, wind directions of 345° to 4°, and sigma azimuths of 11° to 34° at the Hockey 30 m level. The weather was synoptically influenced by a large high pressure system centered over the northern plains.

A helicopter cross-section was performed between 1510 and 1619 EST at a distance of 1.6 km from the plant (Figure 81, 82 and 83). The plume center of mass was calculated to be at a bearing of 175° and an elevation of 534 m above plant base. The calculated plume heights which ranged from 407 m to 504 m for the hours of 1500, 1600 and 1700 were a slight underestimation of the actual plume height as determined by the center of mass of the helicopter cross-section. The calculated mean of 463 m is 13 percent less than observed mean of 534 m.

During this cross-section Johnson recorded only moderately elevated concentrations of SO_2, probably due in part to the high plume heights and plume bearing. Johnson was located at a bearing of 191°; the plume center of mass was at 175°.

A pibal without T-sonde released at 1536 EST showed wind directions to be veering from 316° to 21° in the lowest 350 m above plant base (Figures 84 and 85). The wind direction at plume height was observed to be 3°. Since Figure 82 presents the plume as it would have appeared to an observer viewing it from the plant, the plume centerline was backing with height. This is in disagreement with the pibal observations made during the cross-section. It is likely that the section of the plume below 1000 m was being channeled by a terrain feature, a gap in the first ridge south of the plant.

TABLE 53. CASE STUDY VIII DATA

		SO_2 Hourly Average/Peak (ppb)													
Date	Hour	Tower	Hockey	Kents	Johnson	Munsey	Nashu	Plume Ht.* (m)	Hockey WS-30m (m/sec.)	Hockey WD-30m (deg.)	Hockey σ_θ-30m (deg.)	SO_2 Plant Emission (g/sec.)	Johnson WS-10m (m/sec.)	Johnson WD-10m (deg.)	Johnson σ_θ-10m (deg.)
July 26	6	2/4	0/0	0/0	20/44	7/17	0/0	343	3.3	22	18	1044	0.4	17	85
	7	2/4	0/0	0/0	20/44	7/17	0/0	388	3.6	24	15	1168	1.0	348	54
	8	4/4	0/0	0/0	20/44	1/7	0/0	411	3.8	34	16	1431	1.0	18	58
	9	0/4	0/6	0/0	19/44	1/7	0/0	427	3.6	40	21	1415	0.9	360	66
	10	0/4	0/6	0/0	13/31	0/0	0/0	449	3.5	35	29	1349	1.5	336	49
	11	0/4	0/6	0/0	33/82	1/7	0/0	496	3.6	1	19	1339	1.2	13	59
	12	0/4	0/6	0/0	45/82	0/7	0/0	488	3.5	4	23	1334	2.0	340	49
	13	0/4	0/6	0/0	18/57	0/7	0/0	502	3.8	359	20	1339	1.3	357	73
	14	0/4	0/6	0/0	15/44	0/7	0/0	480	4.1	358	20	1286	1.9	337	50
	15	0/4	0/6	0/0	8/19	0/7	0/0	477	3.8	352	18	1274	1.9	335	53
	16	0/4	0/6	0/0	6/19	0/7	0/0	407	3.2	345	34	1293	2.0	328	45
	17	0/4	0/6	0/0	8/19	0/0	0/0	504	5.0	356	11	1242	2.0	333	36
	18	0/4	0/6	0/0	6/19	0/7	0/0	536	4.2	346	21	1234	2.2	334	21
	19	0/4	0/6	0/0	10/31	0/7	0/0	921	4.2	8	18	1174	1.7	334	37
	20	0/4	0/6	0/0	19/31	0/7	0/0	386	4.0	17	17	1167	1.0	344	43
	21	0/4	1/6	0/0	13/31	0/7	0/0	232	5.1	30	10	1245	0.7	26	75
	22	0/4	4/6	0/0	14/31	0/0	0/0	237	4.7	48	14	1289	0.9	15	55

* Calculated from average heat flux of the 2 stacks.

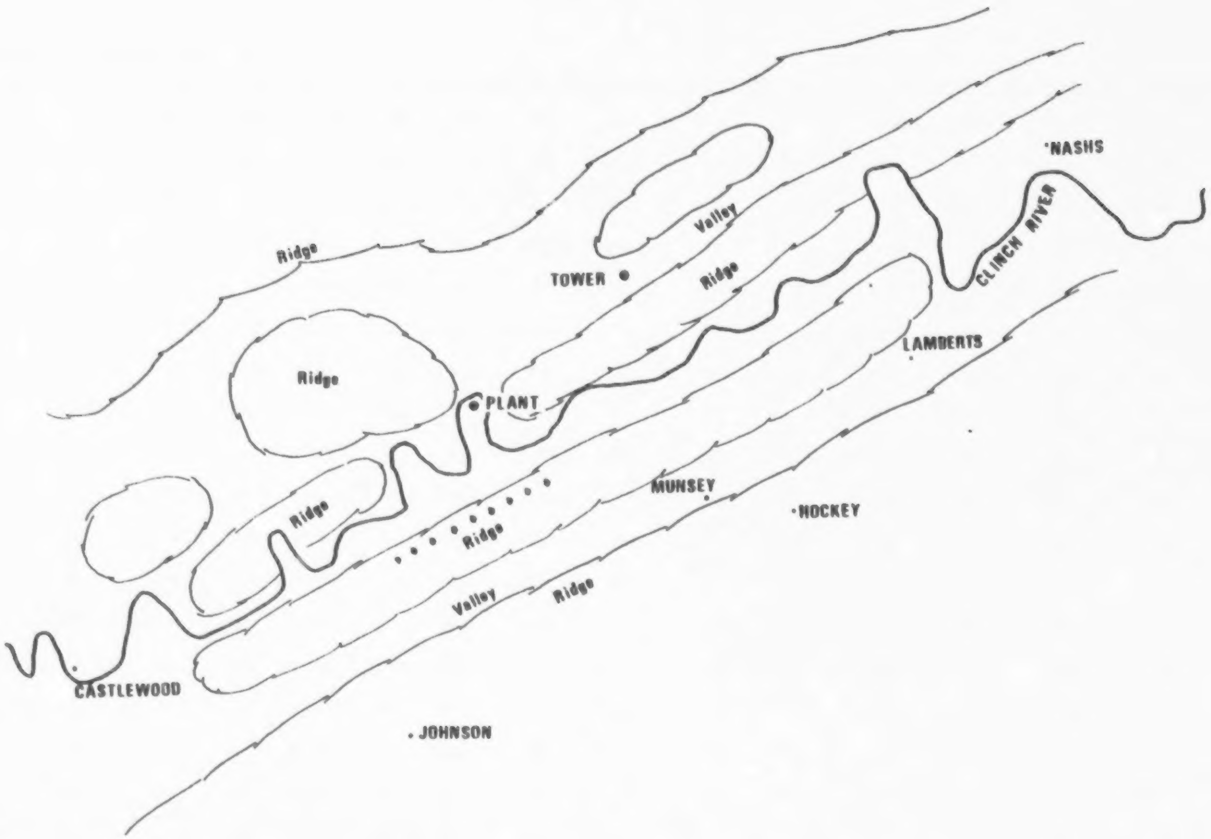

NASHS
CLINCH RIVER
Valley
Ridge
TOWER
Ridge
LAMBERTS
Ridge
PLANT
Ridge
MUNSEY
HOCKEY
Ridge
Valley
Ridge
CASTLEWOOD
JOHNSON

Figure 81. Location of helicopter cross-section (dotted line) - Day 207, 1510-1619.

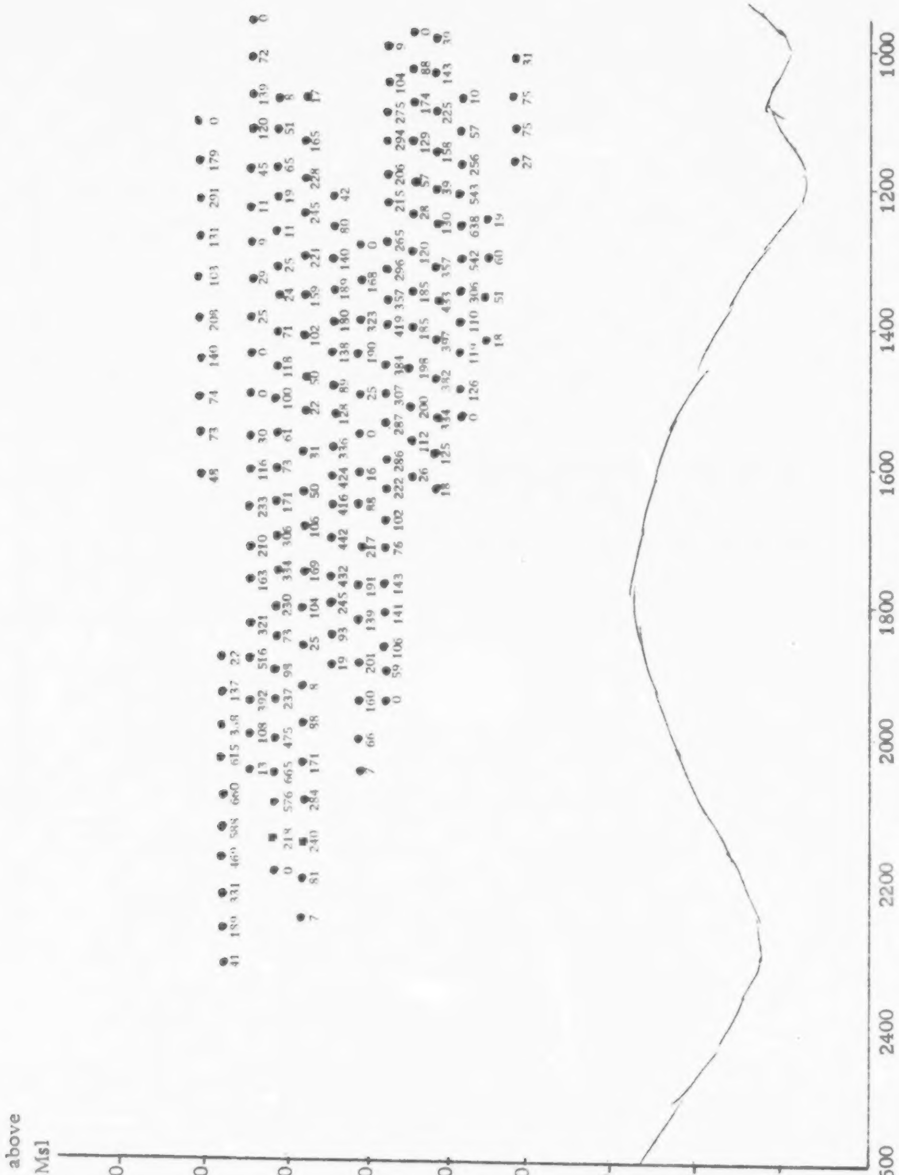


Figure 82. View of helicopter cross-section from plant - Day 207, 1510-1619.

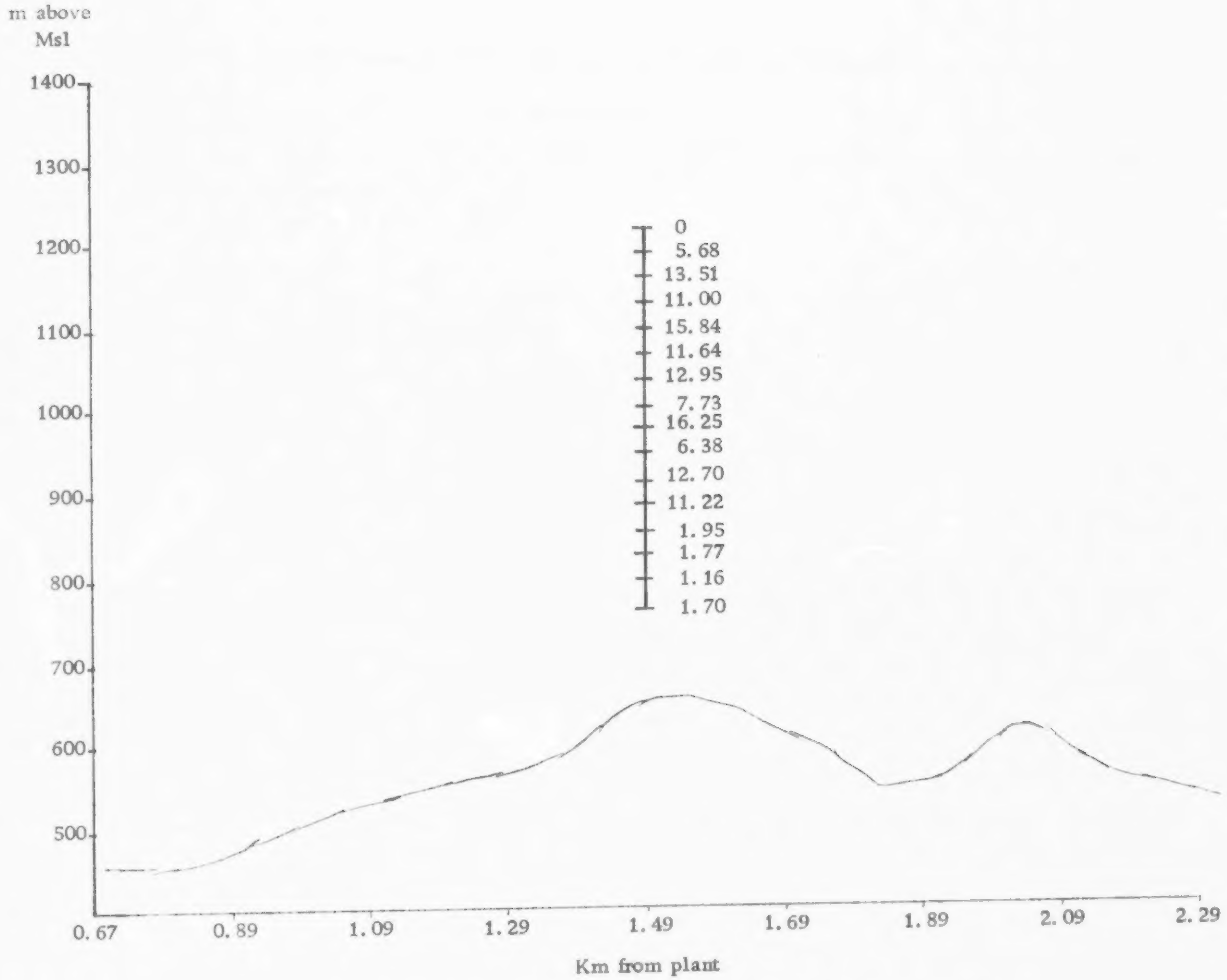


Figure 83. Longitudinal view of helicopter cross-section - Day 207, 1510-1619.

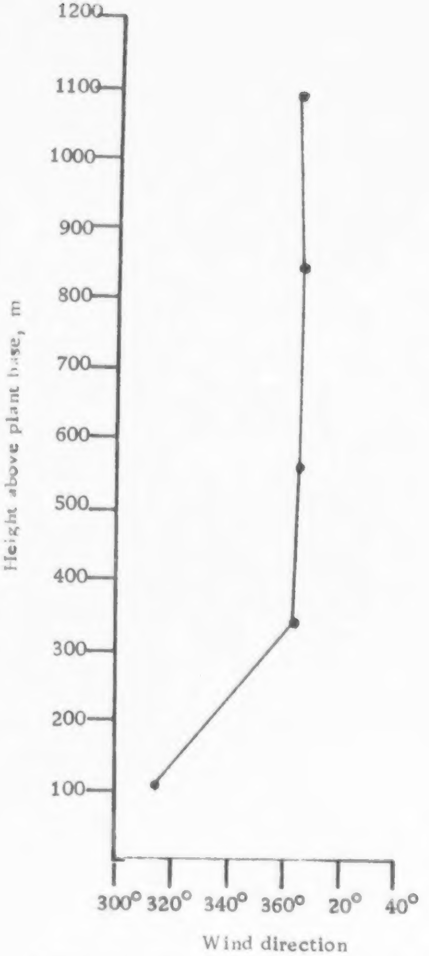


Figure 84. Wind direction profile at 1536 EST, July 26, 1977.

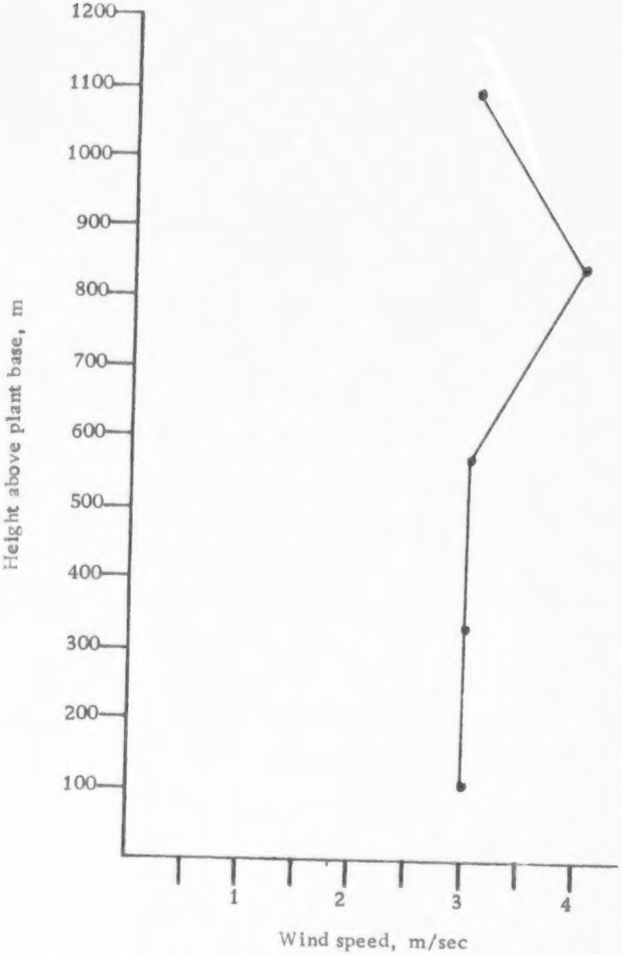


Figure 85. Wind speed (m/s) at 1536 EST, July 26, 1977.

SUMMARY

Terrain influences are evident in the meteorological observations, the ground level measurements of pollutants, and in helicopter measurements of the power plant plume. Frequencies of occurrence of wind direction tabulated at each monitoring site show that each site, located in a valley or a pass where terrain influences are important, experiences a major component of air flow that is aligned with terrain features. Sites in valleys have lowered wind speeds than sites on ridges, and higher turbulence levels, as indicated by the standard deviation of wind direction for a 1-hour period.

Detailed studies of 8 selected cases of measured high SO_2 incidents included 4 situations with high values measured on ridges with flow directed across the ridges, 3 situations with high values measured in valleys due to prolonged fumigation of the plume into the valleys, and 1 situation of terrain channeling of the flow as shown by helicopter cross-sections. These case studies illustrate the nature of the plume behavior problem from a descriptive point of view. The behavior of nitrogen oxide gases in the plume were also studied along with the effects of terrain influences. The NO/NO_x data show evidence of rapid initial transformation of NO to NO_2 within the first 3 km of travel followed by a much slower, almost stagnant rate of transformation beyond this distance out to 15 km.

Section 9

SULFATE ANALYSIS

Sulfate concentrations were determined from hourly samples of particulate collected using hi-vol type monitors at four fixed stations. The sulfate data were obtained in order to characterize sulfate concentrations in the plume and to compare plume concentrations with general background levels. A significant preliminary step in interpreting the sulfate measurements was to separate interfering effects in the measurement process from the influences of ambient air concentrations.

The sulfate measurements include components that were not deposited on the filter during active sampling. One component is the sulfate found in the filter before deployment to the field. This filter background level was determined by analyzing the sulfate level for one out of every 50 filters. Another component is the fallout of sulfate on the filters after exposure to ambient air. This value was determined by measuring the sulfate level on filters that were not exposed to a blower-forced sample of air. At least one such "natural deposition" filter was used with each set of actively sampled filters at each fixed monitoring site.

Figure 86 presents sulfate concentration-wind roses for the fixed monitoring sites. The wind directions at the 30 m Hockey level were used for these analyses. There appears to be no clear trend at any fixed station for elevated sulfate levels with wind directions that would have transported the plume to the station from the plant. However, each station had either a primary or secondary peak of sulfate concentration with wind directions out of the west-southwest, the prevailing wind direction. Perhaps this is an indication of long-range sulfate transport.

It can be concluded from Figure 87 that the amount of sulfate that accumulated on natural deposition filters was a function of time. We have concluded, based on the information shown from this figure, that the variance of the the amount of sulfate fallout on natural deposition filters became too large for useful analysis after approximately 12 days. The standard error of estimate of the data about the linear regression line was 391 μg when considering all the plotted data. However, the standard error of estimate decreased to 281 μg when considering only those cases with exposure times of less than 13 days.

Also shown as open circle data points on Figure 87 are the standard deviations of the fallout for those cases when there were more than one natural deposition filter at a site. In general the standard deviations increased with exposure time. There were 11 cases of multiple natural deposition exposure

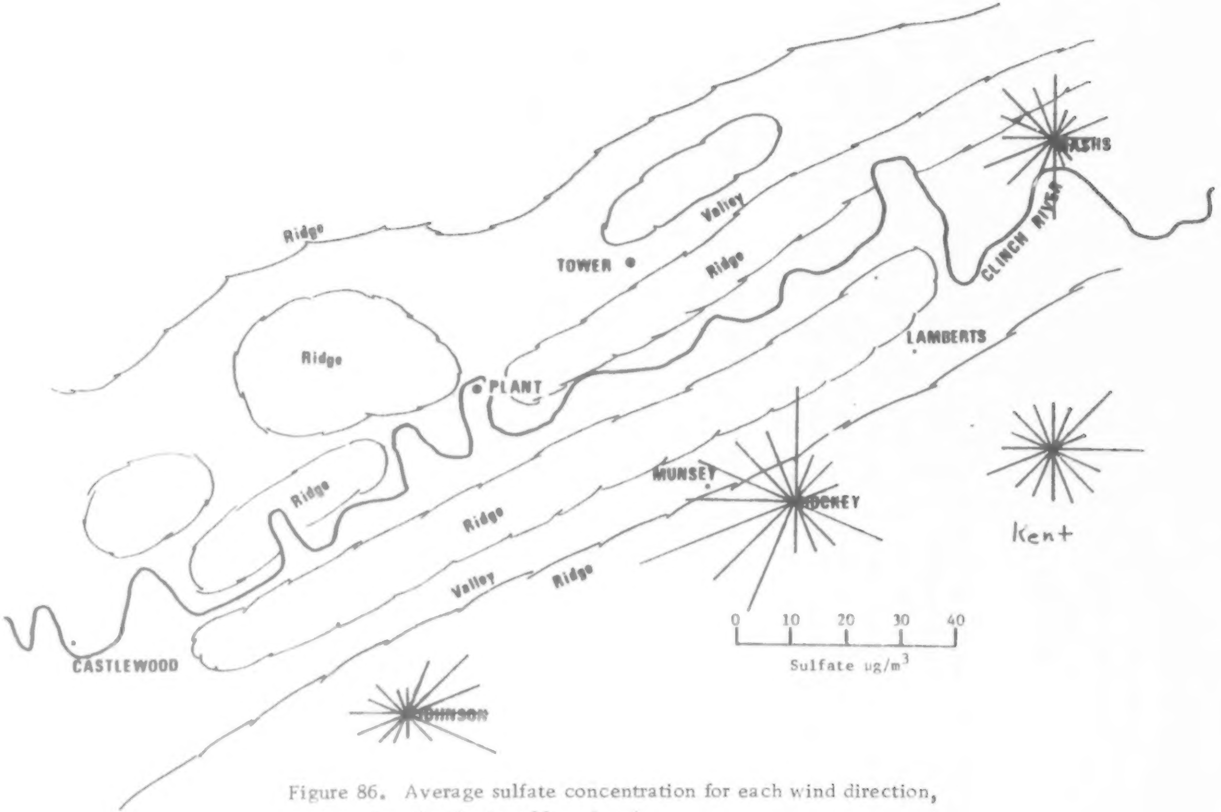

Ridge
TOWER
Valley
Ridge
ASHS
CLINCH RIVER
Ridge
PLANT
LAMBERTS
MUNSEY
OCKEY
Ridge
Ridge
Kent
Valley
Ridge
0
10
20
30
40
Sulfate ug/m³
CASTLEWOOD
OHNSON

Figure 86. Average sulfate concentration for each wind direction, measured at the Hockey 30-m level.

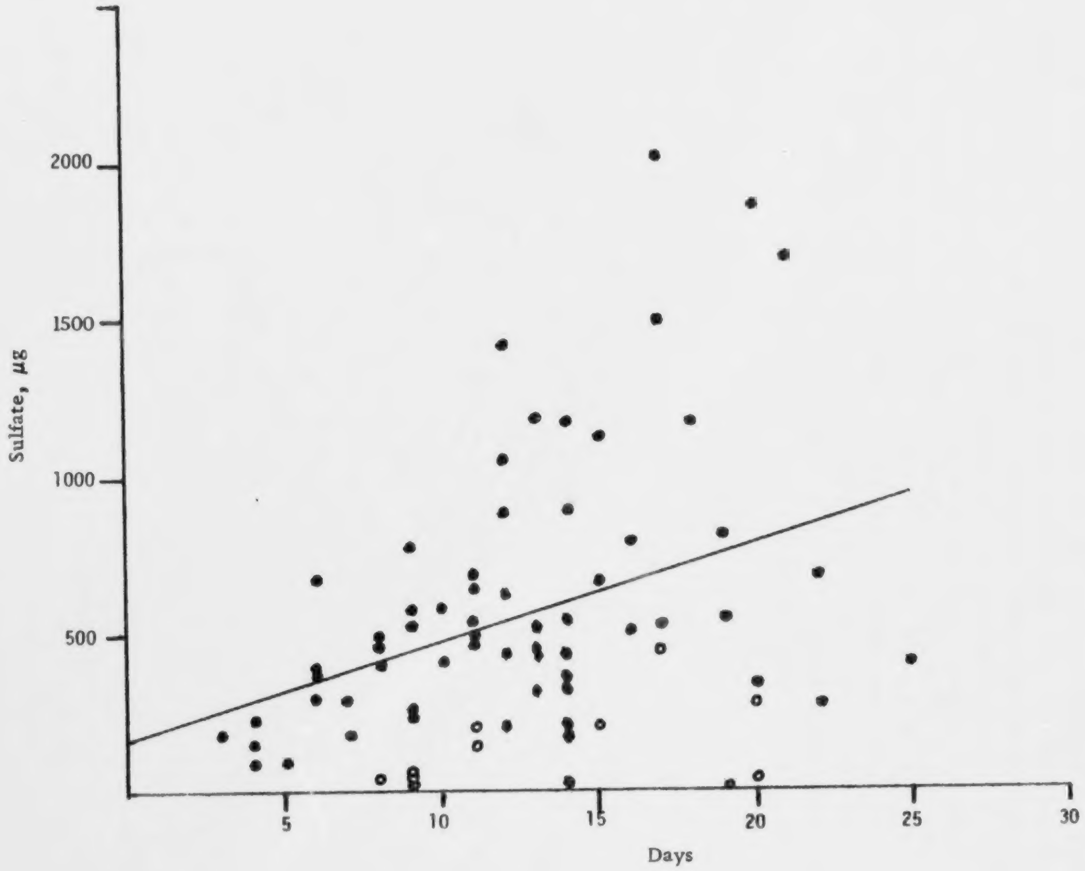
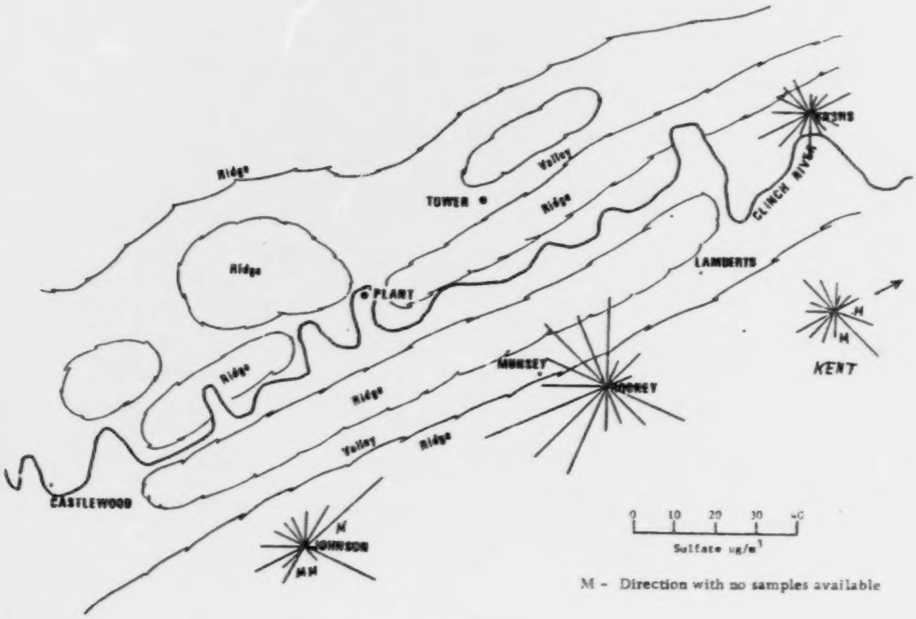


Figure 87. Sulfate mass due to natural deposition on filters vs. exposure time (solid circles) and standard deviation (open circles) of natural fallout where multiple samples were available.

of which 6 were less than 13 days and 5 were 13 days or more. For all 11 cases the standard deviation is 209 µg. For the six cases with less than 13 days exposure the standard deviation is 100 µg. The variations in deposition data at a single site shows that this accounts for a significant part of the variance in the regression analysis of measurements at different sites and times Figure 88 presents pollution roses based only on those cases in which the filters were exposed to ambient air for 12 days or less. It may be noted that there is a preference for higher sulfate concentrations with wind directions from the west-southwest.

Tables 54 to 60 and Figures 89 to 108 pertain to seven cases in which two or more fixed monitoring stations were simultaneously sampling sulfates, and elevated SO_4 concentrations were observed at one or more of the stations. As illustrated in these figures, there appears to be little correlation between SO_4 and SO_2 concentrations. It should be noted that in these figures SO_2 concentrations less than 30 µg/m^3 are close to the measuring threshold of the instrument. Tables 54 to 60 indicate that for these cases wind directions (30 m level at Hockey) were generally from the southwest. There is no clear evidence of stations downwind from the plant receiving higher SO_4 concentrations. This supports the hypothesis that some of the observed sulfate concentrations in the area around the plant came from a distant source, perhaps to the southwest.



M - Direction with no samples available

Figure 88. Average sulfate concentration for each wind direction, measured at the Hockey 30-m level, for filters exposed no more than 12 days.

TABLE 54. DATA ON ESTIMATED BEARING OF THE PLUME, BASED ON 30 M HOCKEY WINDS (JULY 8, 1977)

Date	Time (EST)	Wind Speed (m/s)	Direction (deg.)	Sigma Azimuth (deg.)	Estimated Plume Bearing (deg.)
July 8, 1977	0900	2.3	256	32	76
	1000	1.6	296	38	116
	1100	2.2	283	31	103
	1200	2.0	298	29	118
	1300	2.1	328	43	148
	1400	2.4	327	32	147
	1500	2.2	299	25	119
	1600	2.4	309	16	129
	1700	2.4	242	28	62

TABLE 55. DATA ON ESTIMATED BEARING OF THE PLUME, BASED ON 30 M HOCKEY WINDS (JULY 20, 1977)

Date	Time (EST)	Wind Speed (m/s)	Direction (deg.)	Sigma Azimuth (deg.)	Estimated Plume Bearing (deg.)
July 20, 1977	1000	1.4	297	34	117
	1100	2.6	311	16	131
	1200	1.2	308	62	128
	1300	1.5	325	56	145
	1400	2.3	327	28	147
	1500	2.8	285	30	105
	1600	2.9	296	22	116
	1700	2.8	305	14	125

TABLE 56. DATA ON ESTIMATED BEARING OF THE PLUME, BASED ON 30 M HOCKEY WINDS (JULY 27, 1977)

Date	Time (EST)	Wind Speed (m/s)	Direction (deg.)	Sigma Azimuth (deg.)	Estimated Plume Bearing (deg.)
July 27, 1977	0900	4.6	112	14	292
	1000	4.3	116	15	296
	1100	1.7	135	63	315
	1200	1.7	353	--	173
	1300	0.6	192	91	12
	1400	2.1	--	--	--

TABLE 57. DATA ON ESTIMATED BEARING OF THE PLUME, BASED ON 30 M HOCKEY WINDS (AUGUST 12, 1977)

Date	Time (EST)	Wind Speed (m/s)	Direction (deg.)	Sigma Azimuth (deg.)	Estimated Plume Bearing (deg.)
August 12, 1977	0800	3.6	224	11	44
	0900	3.6	222	10	42
	1000	4.6	232	16	52
	1100	2.7	284	31	104
	1200	3.7	238	20	58
	1300	4.1	219	15	39
	1400	2.7	304	44	124
	1500	2.2	245	44	65
	1600	5.2	302	39	122

TABLE 58. DATA ON ESTIMATED BEARING OF THE PLUME, BASED ON 30 M HOCKEY WINDS (AUGUST 22, 1977)

Date	Time (EST)	Wind Speed (m/s)	Direction (deg.)	Sigma Azimuth (deg.)	Estimated Plume Bearing (deg.)
August 22, 1977	1100	4.9	295	12	115
	1200	3.7	307	31	127
	1300	2.1	275	34	95
	1400	3.0	225	26	45
	1500	1.8	246	35	66
	1600	2.3	321	18	141
	1700	2.3	312	18	132
	1800	3.0	318	17	138

TABLE 59. DATA ON ESTIMATED BEARING OF THE PLUME, BASED ON 30 M HOCKEY WINDS (AUGUST 23, 1977)

Date	Time (EST)	Wind Speed (m/s)	Direction (deg.)	Sigma Azimuth (deg.)	Estimated Plume Bearing (deg.)
August 23, 1977	0900	2.8	232	22	52
	1000	2.5	232	37	52
	1100	4.4	228	16	48
	1200	5.5	224	13	44
	1300	6.1	215	11	35
	1400	6.4	218	13	38
	1500	5.1	224	12	44
	1600	3.9	245	16	65
	1700	2.8	227	17	47

TABLE 60. DATA ON ESTIMATED BEARING OF THE PLUME, BASED ON 30 M HOCKEY WINDS (AUGUST 26, 1977)

Date	Time (EST)	Wind Speed (m/s)	Direction (deg.)	Sigma Azimuth (deg.)	Estimated Plume Bearing (deg.)
August 26, 1977	0800	1.1	104	43	284
	0900	0.4	257	96	77
	1000	0.8	239	56	59
	1100	3.4	216	28	36
	1200	4.4	219	9	39
	1300	4.3	190	19	10
	1400	4.4	199	20	19
	1500	4.1	190	20	10
	1600	4.3	200	18	20
	1700	4.7	183	15	3
	1800	4.3	182	17	2

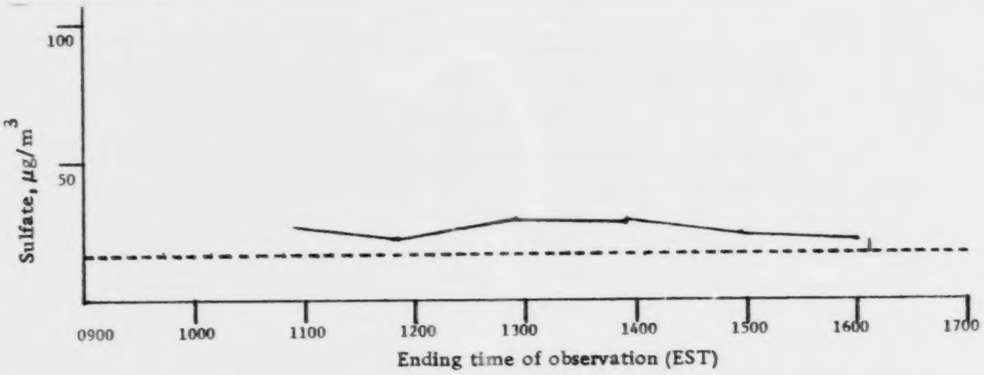


Figure 89. SO_2 (dotted line) and SO_4 concentrations at Hockey for July 8, 1977. (Bearing to plant is 287°)

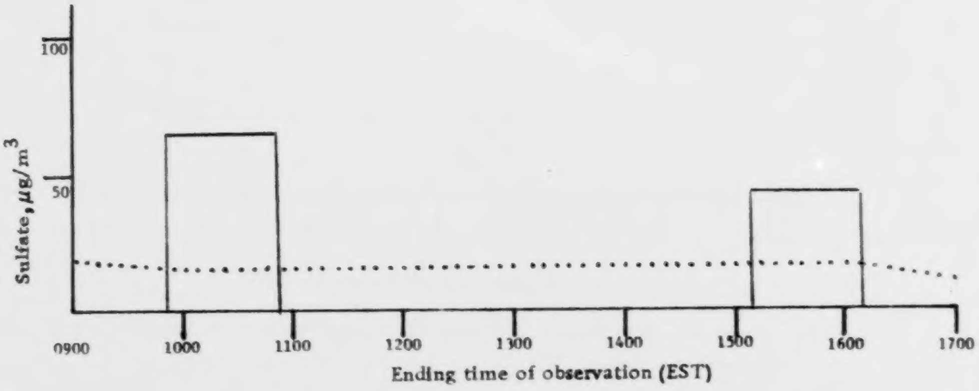


Figure 90. SO_2 (dotted line) and SO_4 concentrations at Johnson for July 8, 1977. (Bearing to plant is 11°)

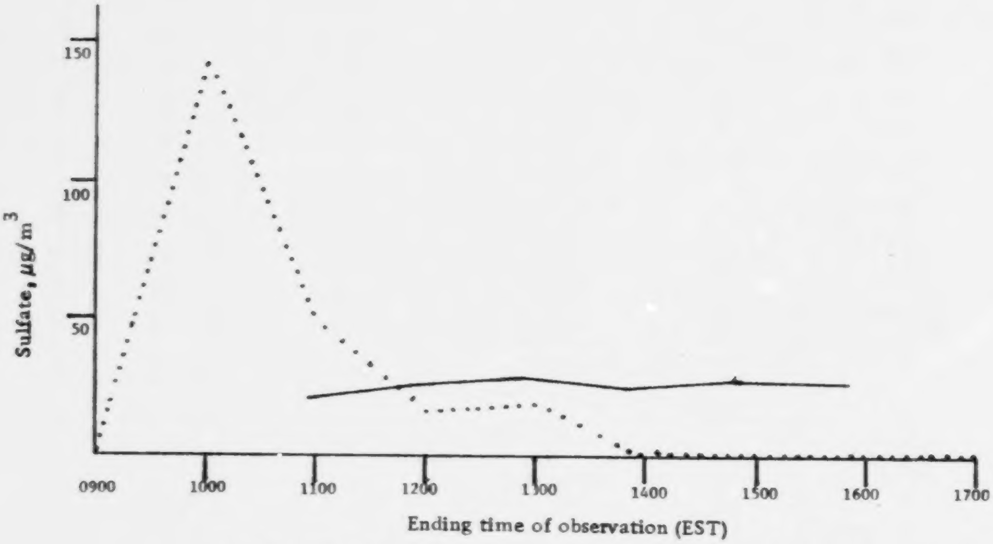


Figure 91. SO_2 (dotted line) and SO_4 concentrations at Nashs for July 8, 1977. (Bearing to plant is 244°)

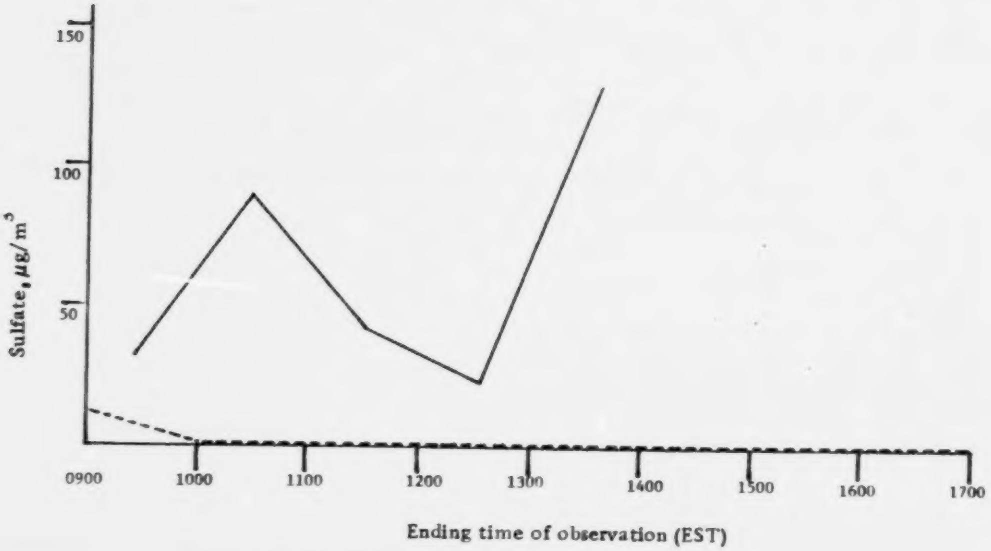


Figure 92. SO_2 (dotted line) and SO_4 concentrations at Hockey for July 27, 1977. (Bearing to plant is 287°)

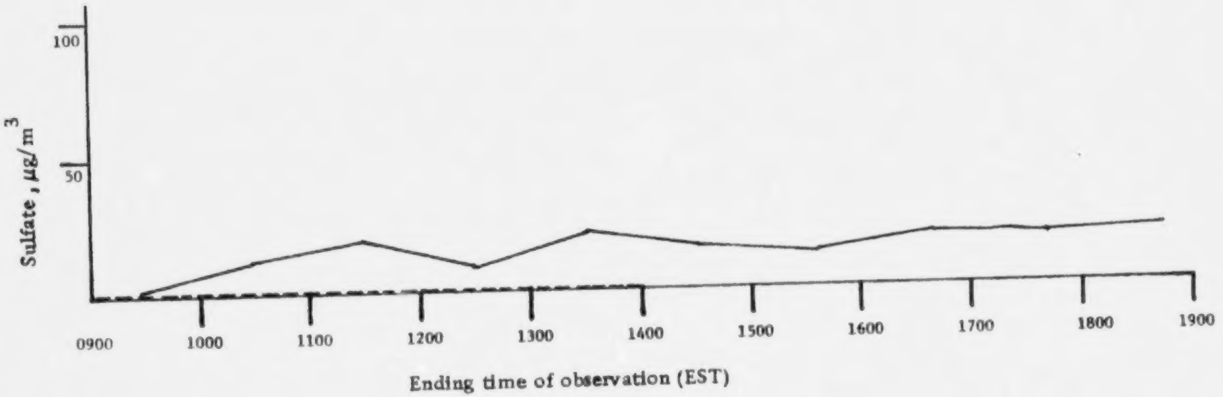


Figure 93. SO_2 (dotted line) and SO_4 concentrations at Kents for July 27, 1977. (Bearing to plant is 248°)

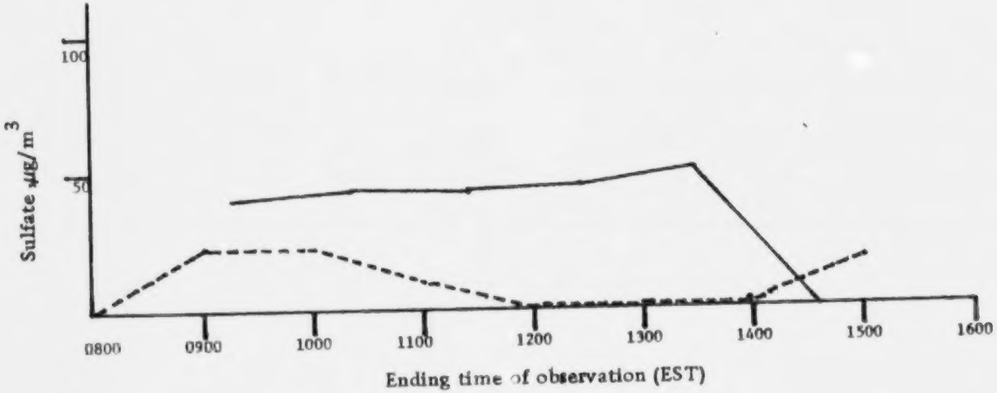


Figure 94. SO_2 (dotted line) and SO_4 concentrations at Hockey for August 12, 1977. (Bearing to plant is 287°)

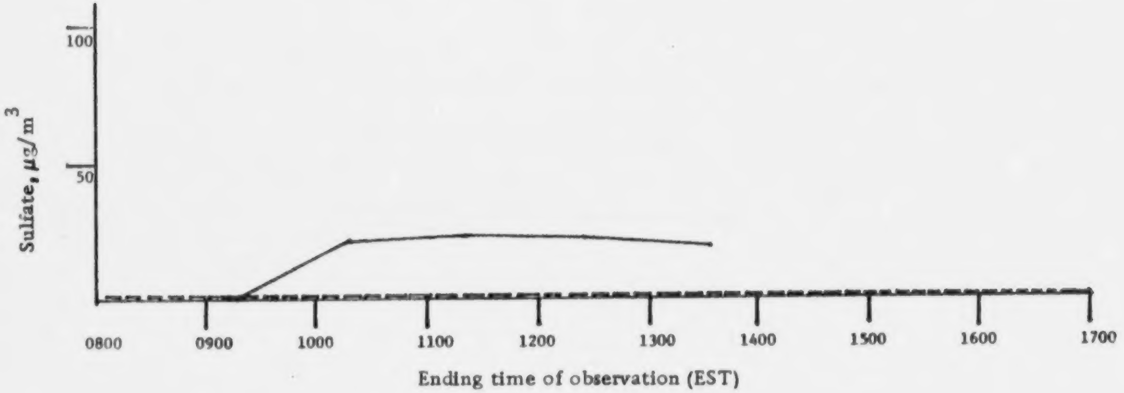


Figure 95. SO_2 (dotted line) and SO_4 concentrations at Kents for August 12, 1977. (Bearing to plant is 248°)

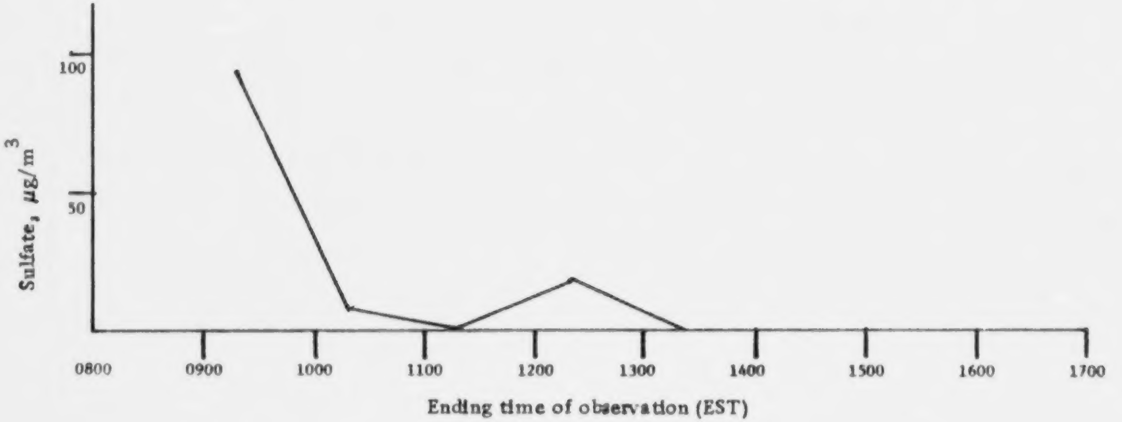


Figure 96. SO_4 concentration at Nashs for August 12, 1977 (SO_2 data was missing). (Bearing to plant is 244°)

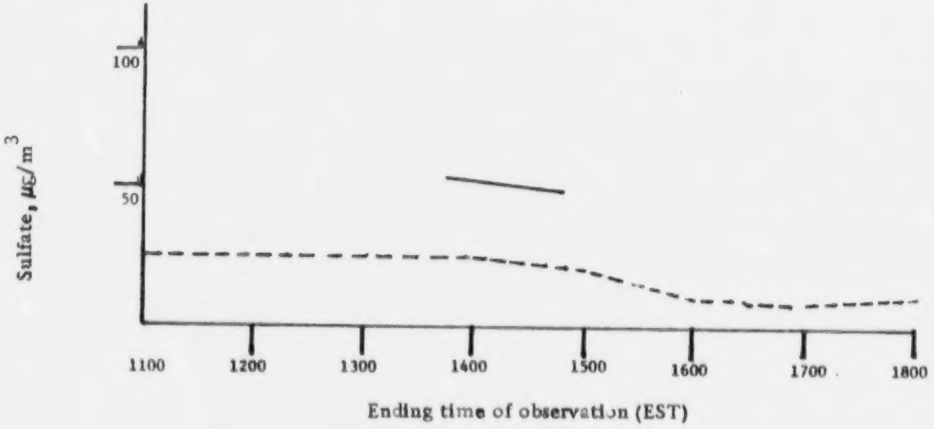


Figure 97. SO_2 (dotted line) and SO_4 concentrations at Hockey for August 22, 1977. (Bearing to plant is 287°)

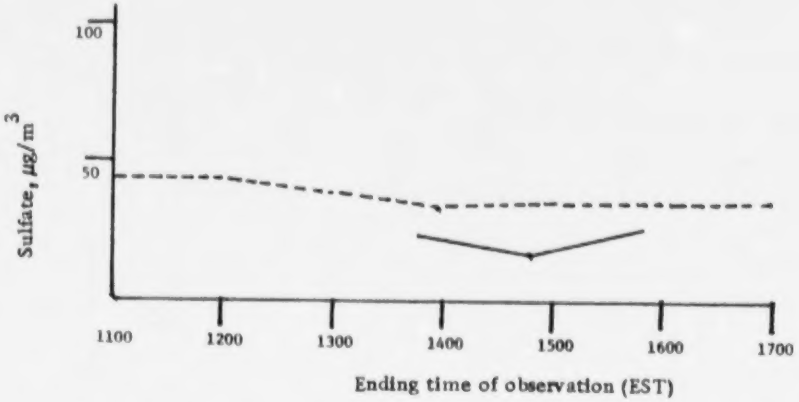


Figure 98. SO_2 (dotted line) and SO_4 concentrations at Johnson for August 22, 1977. (Bearing to plant is 11°)

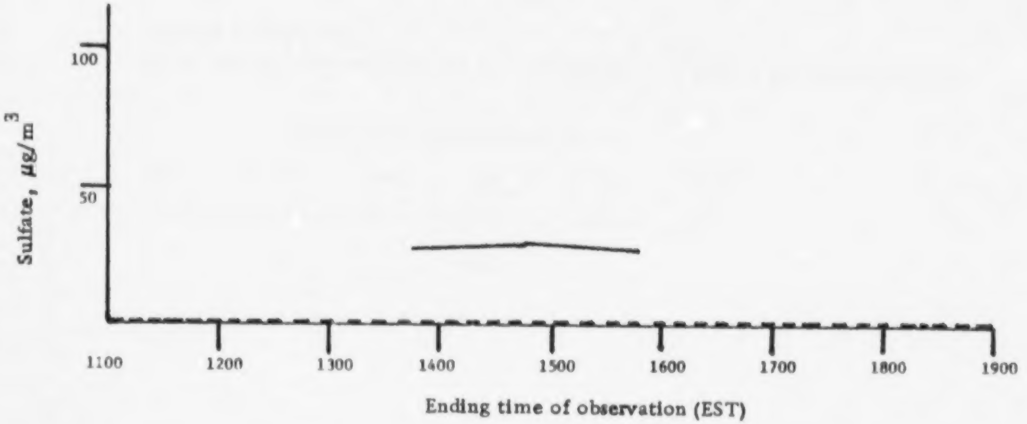


Figure 99. SO_2 (dotted line) and SO_4 concentrations at Kents for August 22, 1977. (Bearing to plant is 248°)

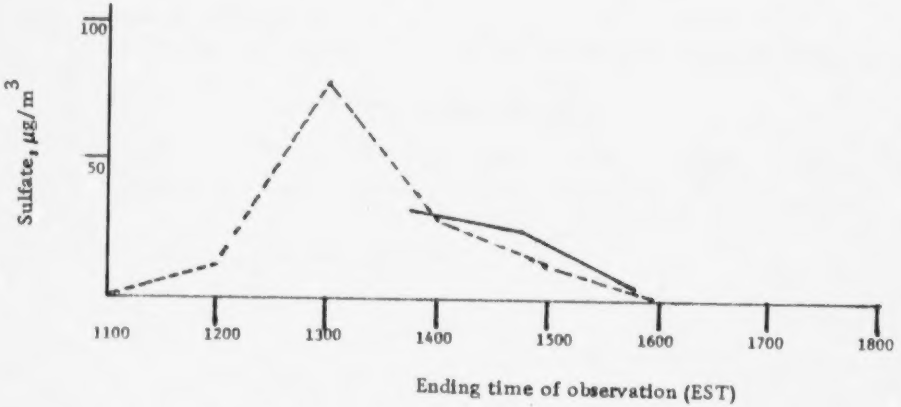


Figure 100. SO_2 (dotted line) and SO_4 concentrations at Nashs for August 22, 1977. (Bearing to plant is 244°)

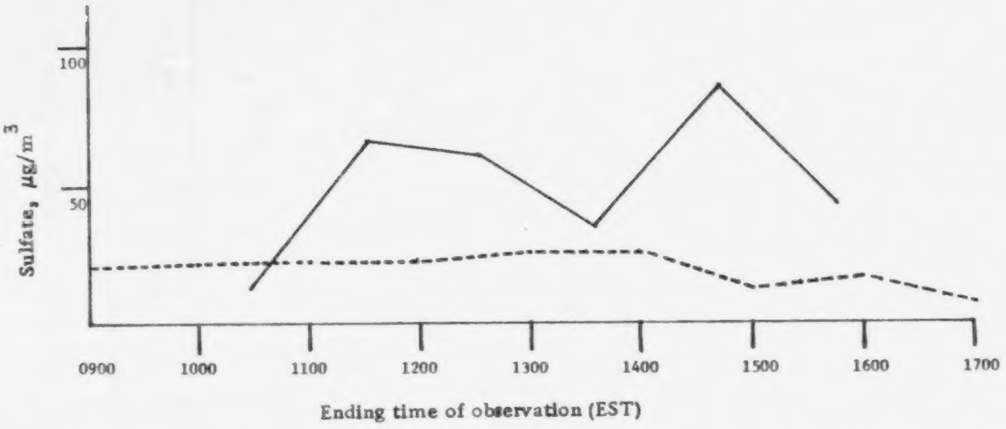


Figure 101. SO_2 (dotted line) and SO_4 concentrations at Hockey for August 23, 1977. (Bearing to plant is 287°)

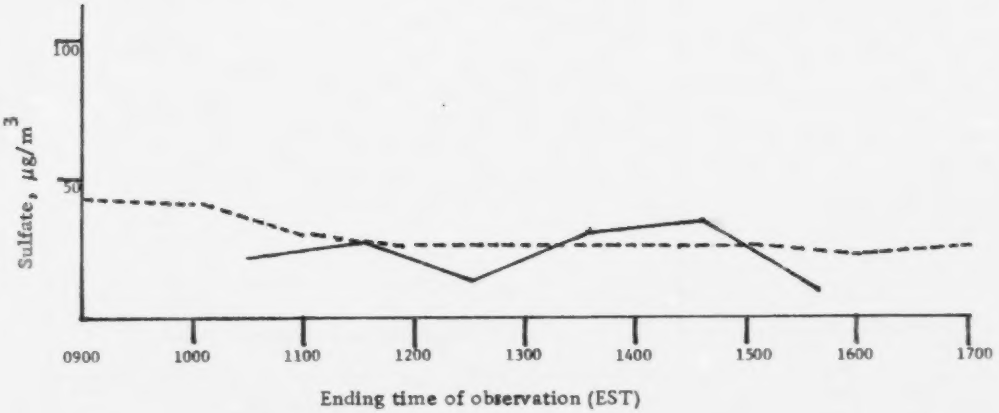


Figure 102. SO_2 (dotted line) and SO_4 concentrations at Johnson for August 23, 1977. (Bearing to plant is 11°)

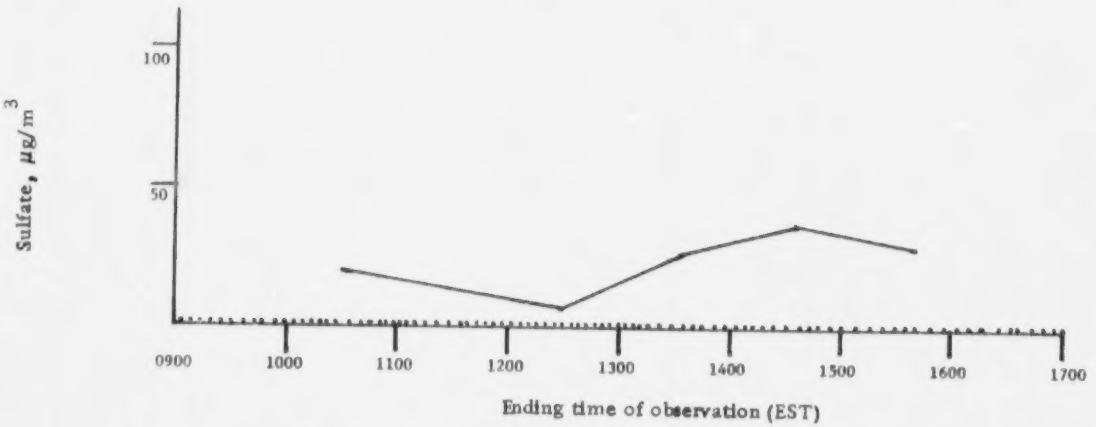


Figure 103. SO_2 (dotted line) and SO_4 concentrations at Kents for August 23, 1977. (Bearing to plant is 248°)

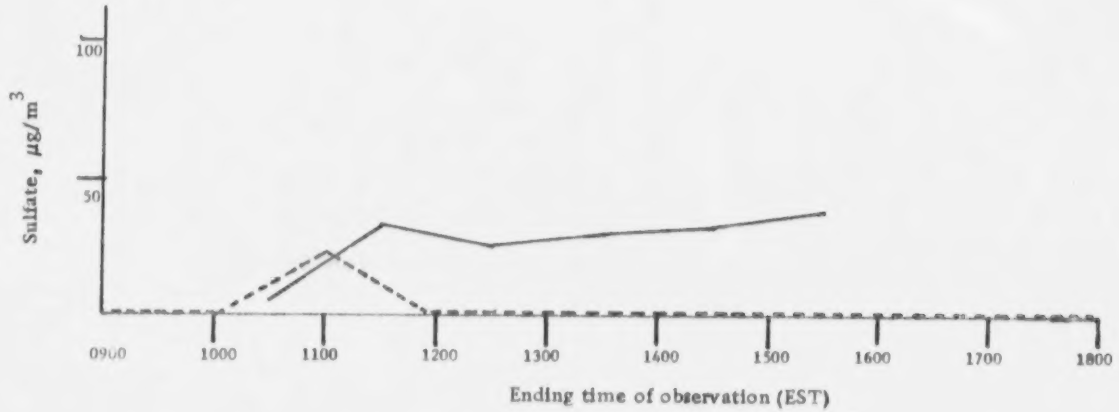


Figure 104. SO_2 (dotted line) and SO_4 concentrations at Nashs for August 23, 1977. (Bearing to plant is 244°)

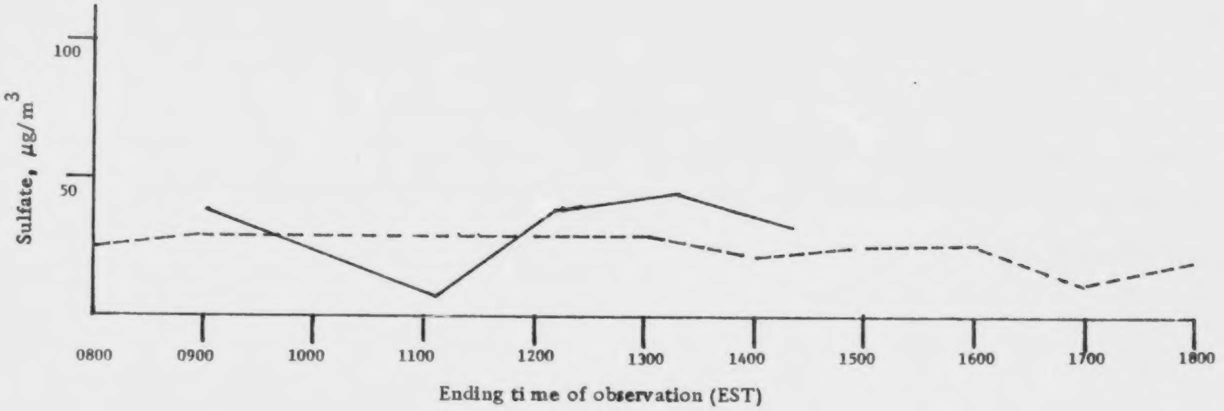


Figure 105. SO_2 (dotted line) and SO_4 concentrations at Hockey for August 26, 1977. (Bearing to plant is 287°)

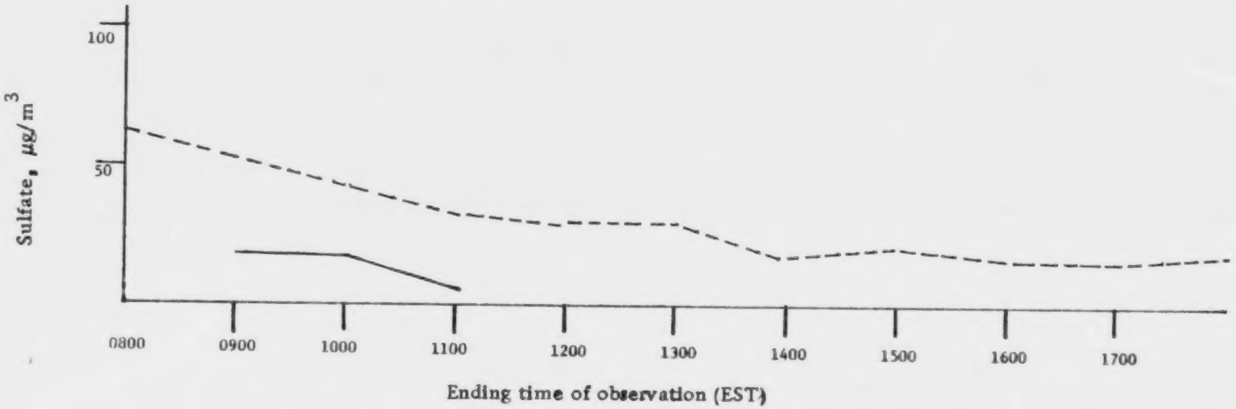


Figure 106. SO_2 (dotted line) and SO_4 concentrations at Johnson for August 26, 1977. (Bearing to plant is 11°)

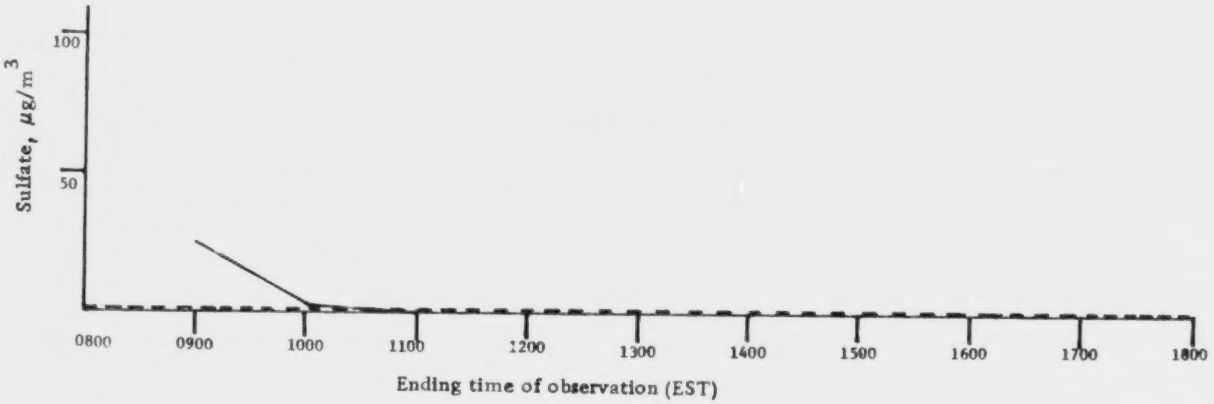


Figure 107. SO_2 (dotted line) and SO_4 concentrations at Kents for August 26, 1977. (Bearing to plant is 248°)

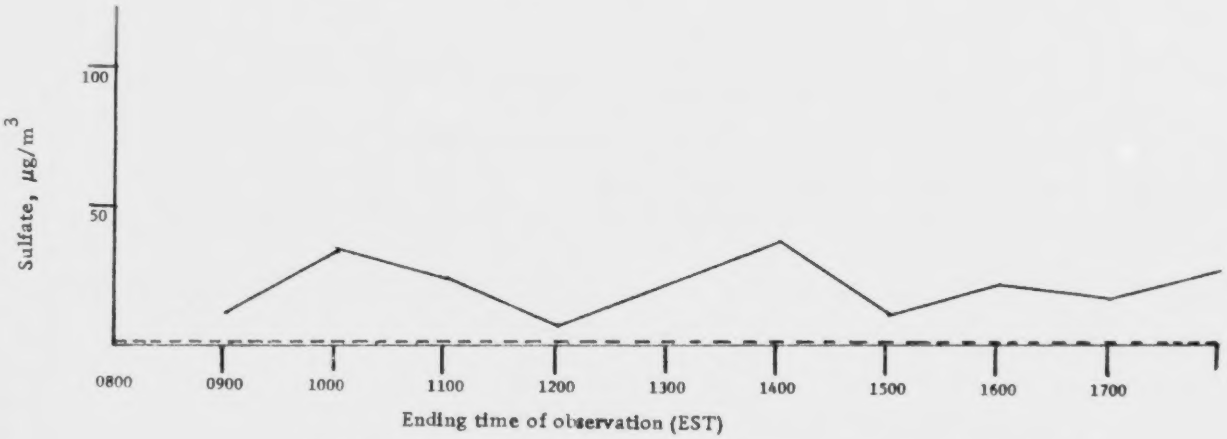


Figure 108. SO_2 (dotted line) and SO_4 concentrations at Nashs for August 26, 1977. (Bearing to Plant is 244°)

SECTION 10

SO_2 DISPERSION ANALYSIS

The Clinch River pollutant and meteorological data sets offer an opportunity for development and validation of dispersion models appropriate for complex terrain. The major goal of this portion of the study was to determine the modifications to a flat terrain Gaussian model which would produce estimates of SO_2 concentrations that would best compare with measured SO_2 values at the eight fixed stations.

The flat terrain model chosen for the study was the PTMTP model from the EPA UNAMAP (User's Network for Applied Modeling of Air Pollution) system. Assumptions made in this model are:

1. Meteorological conditions are steady-state each hour.
2. Dispersion parameters are those presented in the Workbook of Atmospheric Dispersion Estimates.
3. Sources and receptors exist in either flat or gently rolling terrain.
4. No aerodynamic downwash occurs.
5 No wind direction or wind speed shear occurs.
6. The given stability exists from ground-level to well above the top of the plume.

Modifications were made to this model to allow a continuous stream of hourly input values, including wind speed and direction, stability class, mixing height, plume height, and emissions data, and to allow the output of a file of estimated SO_2 concentrations appropriate for the eight stations. The most important modification was the use of the plume heights determined from sounding data described in Section 6 rather than the use of the Briggs' subroutine BEH072.

Wind speed and direction data from the Hockey 30 m level were used as model inputs. Estimated SO_2 emissions from Units 1 and 2 of the plant were used along with the measured SO_2 emissions from Unit 3. When the Unit 3 measurements were missing, the estimated values were utilized (see Section 5).

There is general agreement that stability classifications which must be determined without a measurement of the boundary layer height should be based on the vertical gradient of potential temperature ($\Delta\Theta$) and the wind speed (u) in terms of the ratio $\Delta\Theta/u^2$ (Hanna et al., 1977). Although some T-sonde observations were made and temperature measurements were available from several heights, there was only occasionally sufficient data to define the depth of the boundary layer. As an alternative, we have used the bulk Richardson number (B), which includes the ratio $\Delta\Theta/u^2$ in it, as a measure of stability. Because the scale of this parameter is very much dependent on how it is measured, we decided to compare measurements of B with the Pasquill stability classifications determined by Turner's rules (1964) using cloud measurements from Tri-Cities Airport and wind speeds from the Tower site. The bulk Richardson number was determined using Tower site measurements as follows:

$$B = \frac{g(\partial T/\partial z + \gamma)\overline{z}^2}{Tu^2}$$

In this formulation, the vertical temperature gradient $\partial T/\partial z$ was measured over the 30 m to 0.5 m layer, $\overline{z}$ was taken as 14.75 m, the 4 m temperature was used at T, and u was the 10 m wind speed. γ is the dry adiabatic lapse rate and equal to -0.00976°C/m. Stability classes were determined for both methods for about 250 hours. The distribution of B values for each stability class was analyzed in order to establish ranges of B that could be reasonably associated with each class. The results in Table 61 show how measurements of B compare with corresponding measures of Turner-Pasquill stability classes.

Although the joint distribution does not show mutually consistent stratifications for the two stability measures, there is a general trend among major clusters in the table which shows that more often than not the two distributors agree as to how stable or unstable any given hour is. Out of 255 observations included in the comparison, 121 observations, or about half, are mutually consistent under the selected classifications system shown below. Each of the two methods has advantages, and one cannot be certain for any given hour which methods best characterizes what is influencing the exhaust plume from the plant. The Richardson number is measured closer to the source and may reflect the effect of valley fog and other conditions which are not present at the Tri-Cities Airport. However, the tower is low and within the influence of roughness elements so that it does not represent area-wide effects as well as the airport operations. We have concluded that the onsite Richardson number better represents stability during nighttime and early morning conditions than the remote Airport measurements and have used the premeasured to characterize stability. It may be noted that different ranges of Bulk Richardson would be obtained for different tower heights, and the values given here can only be considered representative of this particular tower height. One should not use the criteria listed below to classify measurements from other towers with different measurement heights.

TABLE 61. DISTRIBUTION OF THE JOINT OCCURRENCES OF CLASSES OF BULK RICHARDSON NUMBER AND PASQUILL STABILITY

	Pasquill Stability Class					
Bulk Richardson No.	A	B	C	D	E	F
<-0.085	9	6	6	0	0	0
-0.085 to <-0.065	2	6	0	0	0	0
-0.065 to <-0.045	5	6	1	1	0	0
-0.045 to <-0.025	5	8	4	3	1	2
-0.025 to <-0.015	2	2	5	4	1	2
-0.015 to <-0.005	3	4	5	10	1	3
-0.005 to <0.005	0	2	3	8	1	1
0.005 to <0.015	0	1	0	13	7	2
0.015 to <0.025	0	0	1	3	2	0
0.025 to <0.045	0	0	0	0	0	2
0.045 to <0.095	1	0	0	4	0	5
≥0.095	8	5	4	6	1	65

Based on the results in Table 61, the following ranges of B were established for determining an hourly stability class for model input:

Class	Range of Bulk Richardson Number
A	$B \leq -0.07$
B	$-0.07 < B \leq -0.03$
C	$-0.03 < B < -0.005$
D	$-0.005 < B \leq 0.01$
E	$0.01 < B \leq 0.10$
F	$B > 0.10$

The parcel method was used to obtain hourly mixing heights from the temperature profiles described in Section 7. A profile of mixing ratio (g/kg) from the same rawinsonde station as the termperature profile was also available for each hour for use in determining the mixing condensation level. Below the mixing condensation level the parcel is lifted dry adiabatically and above this level the parcel is lifted moist adiabatically. When the parcel, lifted from the surface becomes 1°C colder than the profile temperature, the mixing height has been determined.

The period modeled extended from Julian Day 287 of 1976 through Julian Day 273 of 1977. The first model run was made with no further modification to the program (i.e., this was a flat terrain model run). The next five model runs each involved the implementation of a plume height adjustment over terrain elevated above the plant base. The five models employed the following five plume height adjustments:

1. CRSTER adjustment (USEPA 1977) - plume height is decreased by the full amount of the terrain elevation difference between plant and receptor for all stability classes.

2. NOAA adjustment (Van der Hoven et al. 1972) - plume height is decreased by the full amount of the elevation difference for stable conditions only. No adjustment for neutral and unstable conditions.

3. VALLEY adjustment (Burt 1977) - plume height is decreased by the full amount of the elevation difference for stable conditions but the plume is not allowed to approach the terrain any closer than 10 m. No adjustment for neutral and unstable conditions.

4. ERT-LAPPES adjustment (Egan 1975 and Slowik et al. 1977) - plume height is decreased by half the elevation difference for unstable and neutral conditions and by the amount Fz for stable conditions, where z is the full elevation difference and $F = 1$ for plume heights $(H) > 1.7z$, $F = 0.65$ for plume heights $(H) \leq z$, and $F = 0.65 + \frac{H-z}{2z}$ for $z < H < 1.7z$.

5. GEOMET adjustment (Koch 1978) - plume height is reduced by 60 percent of the elevation difference for stable conditions, but the plume height is never allowed to become less than 40 percent of the unadjusted value. No adjustment for neutral and unstable conditions.

After each model run a statistics program was employed to produce a cumulative frequency distribution of the estimated concentrations for each station. These distributions could then be compared with the distributions of measured values. The program also computed paired statistics such as the correlation coefficient, slope and intercept resulting from linear regression and the root-mean-square error. The highest and second highest measured and computed concentrations at each station were also compared. All statistics except the cumulative frequency distributions were computed separately for stable, neutral and unstable conditions as well as for all stabilities combined.

The plume height for each stack was computed using a multiple stack adjustment, which was found to be the best technique. The LAPPES σ_y adjustment (Slowik et al. 1977) involves multiplying the appropriate Pasquill-Gifford value by a factor of 1.43 for unstable and neutral conditions. A multiplier of $(1.43/0.4\ u^{0.3})$ is used for stable conditions, where u is the wind speed. These factors result from the LAPPES program conducted in Pennsylvania from 1967 to 1971. The GEOMET σ_y adjustment (Koch 1978) involves the use of a multiplier of 3.0 for neutral and stable conditions and a multiplier of 2.0 for slightly unstable conditions. No adjustments are made for unstable conditions. The values were largely derived from plume measurements in the vicinity of Maryland power plants. The Clinch River helicopter data also provide a basis for little or no modification to σ_y for unstable conditions. A model using these parameters along with the GEOMET plume height adjustment has been validated against measured concentrations at several Pennsylvania power plants in complex terrain (Koch 1977).

In addition to the σ_y adjustments, the σ_z formulation suggested by F.B. Smith (1972) was applied, which for the average roughness of the terrain in the vicinity of the Clinch River plant is a factor of 1.5 increase over the Pasquill-Gifford values. An initial plume dilution factor and the use of a power law to extrapolate the transport wind speed from the Hockey 30 m station elevation to plume height were included in the additional model runs. The initial dilution factor accounts for the spread of the plume during the entrainment stage. A method proposed by Pasquill (1976) was employed which involves modification of the vertical dispersion parameters as follows:

$$\sigma_z = \sqrt{\sigma_{z(I)}^2 + H^2/10}$$

where $\sigma_{z(I)}$ is the original value unmodified by the hot plume entrainment process and H is the plume rise. The wind speed at plume height was estimated by extrapolating the Hockey 30 m wind speed to plume height using a power law with the exponents (p) dependent on stability class:

$$U_p = U_H \left(\frac{H}{z_H} \right)^p$$

where U_p is the wind speed at plume height, U_H is the Hockey 30 m wind speed, H is the plume height and z_H is the elevation of the Hockey 30 m station above the plant. There is much uncertainty in this procedure as no set of exponents appropriate for complex terrain exist. The following exponent values were employed which resulted from the analysis of meteorological tower data from several flat-to-rolling-terrain sites (see analysis in Section 7).

Pasquill-Turner Stability Class	p
A	0.10
B	0.10
C	0.10
D (day)	0.12
D (night)	0.21
E	0.35
F	0.49

The final model run employed the recommendations of Pasquill (1976) for using measured σ_A. This method has been described in Section 6; the method was employed along with the GEOMET plume height adjustment and the wind extrapolation technique. The standard Pasquill-Gifford σ_z was employed.

Two statistics (root-mean-square error and correlation coefficient) from the results of the aforementioned model runs appear in Tables 62 through 69. Model calculations could only be performed when all necessary input data were available. Paired comparisons of measured SO_2 concentrations and model estimates could only be made when both were available. Table 70 shows the number of comparisons that were performed for each station and for each stability. Table 71 presents a comparison of the highest and second highest 1-hour average SO_2 concentrations produced for each station by four of the modeling techniques along with the highest and second highest measured values.

For the purposes of statistical comparison, background SO_2 concentrations were added to the model estimates. A background value was estimated for each hour by the following procedure:

1. All available fixed-station SO_2 observations for each hour were used to compute a mean and standard deviation.

TABLE 62. RMSE OF MODEL TO MEASUREMENT COMPARISONS FOR ALL STABILITIES

Station	Flat Terrain	CRSTER H	NOAA H	GEOMET H	VALLEY H	ERT-LAPPES H	ERT-LAPPES H GEOMET σ_y	ERT-LAPPES H LAPPES σ_y	GEOMET H LAPPES σ_y	GEOMET H GEOMET σ_y	GEOMET H GEOMET σ_y F.B. Smith σ_z	GEOMET H GEOMET σ_y Pasquill-Dilution	GEOMET H GEOMET σ_y Wind Extrap-olation	GEOMET H σ_y = [illegible] Wind Extrap-olation
Tower	40.2	136.1	117.2	40.4	117.2	93.1	56.7	69.5	33.3	36.5	38.4	36.4	31.0	28.2
Castle	15.6	15.6	15.6	15.6	15.6	15.6	15.7	14.0	14.0	15.7	15.8	15.7	14.3	12.9
Hockey	22.2	369.5	365.3	42.1	354.0	80.7	61.5	60.5	30.4	30.6	44.9	39.2	22.8	24.1
Munsey	23.2	98.1	88.0	26.5	88.0	60.0	62.8	58.7	25.0	25.9	34.2	26.6	20.9	18.7
Lambert	11.6	55.9	52.6	16.9	52.6	38.0	42.2	41.2	14.7	14.0	28.8	15.8	9.7	9.0
Johnson	31.0	263.9	261.7	47.8	255.2	65.3	61.2	56.8	40.7	48.6	50.3	51.8	31.7	20.3
Kents	8.1	73.6	73.2	26.2	72.5	33.9	19.9	18.2	14.1	15.5	18.0	17.3	9.6	9.5
Nashs	10.2	23.7	21.4	11.9	21.4	23.2	15.8	17.7	10.0	9.6	12.3	9.9	8.0	8.3

NOTE: The following definitions are applicable to Tables 62 to 69 and 71.

Flat Terrain - UNAMAP PTMTP Model, basis model to which modifications are made.

CRSTER H - Plume height is level; height above ground is reduced by amount that terrain elevation exceeds plant elevation (full terrain adjustment).

NOAA H - Plume height is level (i.e., full terrain adjustment applies) for stable conditions; plume height is fixed above ground level for neutral and unstable conditions (no terrain adjustment).

GEOMET H - Plume height is reduced by 60 percent of the amount that terrain elevation exceeds plant base, up to a maximum of 40 percent of the unadjusted plume height, under stable conditions; no terrain adjustment is applied for neutral and unstable conditions.

VALLEY H - Same as NOAA H, except that plume height is never less 10 m above ground level.

ERT-LAPPES H - Plume height is reduced by 50 percent of the amount that terrain elevation exceeds plant base under unstable and neutral conditions; under stable conditions the plume height (H) is reduced when the terrain elevation exceeds the plant base elevation by the amount F_z, where z is the elevation difference and:

$$F = \begin{cases} 1.0 & , H/z > 1.7 \\ 0.65 & , H/z \leq 1.0 \\ 0.65 + 0.5\ (H-z)/z, & 1.0 < H/z \leq 1.7 \end{cases}$$

GEOMET σ_y - The Pasquill-Gifford (P-G) σ_y values are multiplied by 3 for stable and neutral conditions and by 2 for slightly unstable conditions (Pasquill stability class C); no adjustment is made for unstable conditions.

LAPPES σ_y - The P-G σ_y values are multiplied by 1.43 for all stabilities and also divided by $0.4 \mu^{0.3}$ (μ = wind speed) for stable conditions.

F.B. Smith σ_z - The P-G σ_z values are multiplied by 1.5 to account for the average terrain roughness.

Pasquill Dilution - The P-G σ_z values are increased by a dilution factor which is a function of computed plume height (above plant base, uncorrected for terrain factors) as follows:

$$(\sigma_z^2 + 0.1H^2)^{0.5}$$

Wind Extrapolation - Wind at plume height estimated by power law extrapolation of Hockey 30 m wind using exponents derived from selected observations.

TABLE 63. CORRELATION OF MODEL TO MEASUREMENT COMPARISONS FOR ALL STABILITIES

Station	Flat Terrain	CRSTER H	NOAA H	GEOMET H	VALLEY H	ERT-LAPPES H	ERT-LAPPES H GEOMET σ_y	ERT-LAPPES H LAPPES σ_y	GEOMET H LAPPES σ_y	GEOMET H GEOMET σ_y	GEOMET H GEOMET σ_y F.B. Smith σ_z	GEOMET H GEOMET σ_y Pasquill-Dilution	GEOMET H GEOMET σ_y Wind Extrap-olation	GEOMET H $\sigma_y = f\sigma_A x$ Wind Extrap-olation
Tower	0.15	0.20	0.13	0.18	0.11	0.26	0.30	0.30	0.20	0.18	0.25	0.17	0.19	0.25
Castle	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.34	0.34	0.27	0.27	0.27	0.33	0.47
Hockey	0.15	0.03	0.03	0.08	0.03	0.05	0.08	0.07	0.10	0.11	0.09	0.09	0.14	0.13
Munsey	0.16	0.04	0.02	0.14	0.02	0.08	0.16	0.13	0.15	0.15	0.13	0.15	0.18	0.20
Lambert	0.32	0.07	0.07	0.22	0.07	0.11	0.10	0.10	0.25	0.26	0.13	0.23	0.36	0.51
Johnson	0.08	0.14	0.13	0.06	0.13	0.07	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.14
Kents	0.29	0.03	0.03	0.08	0.03	0.06	0.13	0.13	0.17	0.16	0.14	0.14	0.26	0.26
Nashs	0.35	0.18	0.19	0.31	0.19	0.18	0.29	0.25	0.30	0.40	0.34	0.40	0.46	0.41

TABLE 64. RMSE OF MODEL TO MEASUREMENT COMPARISONS FOR UNSTABLE CONDITIONS

Station	Flat Terrain	CRSTER H	NOAA H	GEOMET H	VALLEY H	ERT-LAPPES H	ERT-LAPPES H GEOMET σ_y	ERT-LAPPES H LAPPES σ_y	GEOMET H LAPPES σ_y	GEOMET H GEOMET σ_y	GEOMET H GEOMET σ_y F.B. Smith σ_z	GEOMET H GEOMET σ_y Pasquill-Dilution	GEOMET H GEOMET σ_y Wind Extrap-olation	GEOMET H $\sigma_y = f\sigma_A x$ Wind Extrap-olation
Tower	100.2	140.9	100.2	100.2	100.2	139.0	115.0	106.1	75.7	88.3	75.4	87.7	67.8	53.0
Castle	61.4	61.4	61.4	61.4	61.4	61.4	61.4	46.7	46.7	61.4	61.4	61.1	48.5	29.5
Hockey	52.5	94.7	52.5	52.5	52.5	94.7	86.8	77.8	44.8	54.0	57.2	54.3	43.1	41.8
Munsey	63.0	118.5	63.0	63.0	63.0	118.5	117.6	115.0	63.9	68.2	82.1	69.5	54.6	43.9
Lambert	30.6	41.5	30.6	30.6	30.6	41.5	32.2	32.2	23.8	20.2	20.4	20.3	16.5	18.8
Johnson	77.3	91.3	77.3	77.3	77.3	89.2	81.1	80.5	57.5	71.5	71.6	71.5	58.1	21.6
Kents	9.0	24.4	9.0	9.0	9.0	24.4	14.3	18.1	7.8	8.1	8.1	8.1	6.9	7.3
Nashs	22.2	28.6	22.2	22.2	22.2	28.6	22.6	23.2	17.6	19.1	19.0	19.1	15.9	14.4

TABLE 65. CORRELATION OF MODEL TO MEASUREMENT COMPARISONS FOR UNSTABLE CONDITIONS

Station	Flat Terrain	CRSTER H	NOAA H	GEOMET H	VALLEY H	ERT-LAPPES H	ERT-LAPPES H GEOMET σ_y	ERT-LAPPES H LAPPES σ_y	GEOMET H LAPPES σ_y	GEOMET H GEOMET σ_y	GEOMET H GEOMET σ_y F.B. Smith σ_z	GEOMET H GEOMET σ_y Pasquill-Dilution	GEOMET H GEOMET σ_y Wind Extrapolation	GEOMET H $\sigma_y = f\sigma_A x$ Wind Extrapolation
Tower	0.20	0.23	0.20	0.20	0.20	0.23	0.18	0.25	0.22	0.15	0.19	0.15	0.17	0.27
Castle	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	0.00
Hockey	0.19	0.31	0.19	0.19	0.19	0.31	0.24	0.33	0.21	0.17	0.16	0.17	0.18	0.19
Munsey	0.09	0.09	0.09	0.09	0.09	0.09	0.01	0.10	0.09	0.08	0.07	0.08	0.09	0.12
Lambert	0.09	0.25	0.09	0.09	0.09	0.25	0.31	0.31	0.25	0.28	0.28	0.28	0.30	0.30
Johnson	0.13	0.28	0.13	0.13	0.13	0.21	0.19	0.23	0.17	0.13	0.13	0.13	0.13	0.29
Kents	0.05	0.01	0.05	0.05	0.05	0.01	0.03	0.02	0.07	0.06	0.06	0.06	0.08	0.07
Nashs	0.10	0.07	0.10	0.10	0.10	0.07	0.09	0.10	0.13	0.12	0.12	0.12	0.15	0.15

TABLE 66. RMSE OF MODEL TO MEASUREMENT COMPARISONS FOR NEUTRAL CONDITIONS

Station	Flat Terrain	CRSTER H	NOAA H	GEOMET H	VALLEY H	ERT-LAPPES H	ERT-LAPPES H GEOMET σ_y	ERT-LAPPES H LAPPES σ_y	GEOMET H LAPPES σ_y	GEOMET H GEOMET σ_y	GEOMET H GEOMET σ_y F.B. Smith σ_z	GEOMET H GEOMET σ_y Pasquill-Dilution	GEOMET H GEOMET σ_y Wind Extrapolation	GEOMET H $\sigma_y = f\sigma_A x$ Wind Extrapolation
Tower	28.4	136.4	20.4	28.4	28.4	134.7	61.8	106.0	28.2	28.3	27.4	28.1	28.4	28.3
Castle	6.6	6.6	6.6	6.6	6.6	6.6	7.4	6.6	6.6	7.4	8.0	7.4	7.1	7.0
Hockey	11.0	110.5	11.0	11.0	11.0	110.5	92.8	90.3	10.1	10.0	18.1	10.3	9.2	8.8
Munsey	8.2	57.3	8.2	8.2	8.2	55.9	92.6	77.1	8.1	7.5	19.2	7.9	7.2	7.0
Lambert	9.4	36.7	9.4	9.4	9.4	36.1	20.2	30.3	8.5	6.4	9.9	6.7	5.6	6.6
Johnson	11.6	66.5	11.6	11.6	11.6	45.7	26.0	39.9	11.5	11.4	12.4	11.4	11.3	11.8
Kents	10.1	12.5	10.1	10.1	10.1	12.5	10.4	11.5	9.6	9.2	9.3	9.3	8.9	9.4
Nashs	10.8	20.5	10.8	10.8	10.8	20.3	13.1	17.8	9.8	7.5	9.5	7.6	6.4	7.6

TABLE 67. CORRELATIONS OF MODEL TO MEASUREMENT COMPARISONS FOR NEUTRAL CONDITIONS

Station	Flat Terrain	CRSTER H	NOAA H	GEOMET H	VALLEY H	ERT-LAPPES H	ERT-LAPPES H GEOMET σ_y	ERT-LAPPES H LAPPES σ_y	GEOMET H LAPPES σ_y	GEOMET H GEOMET σ_y	GEOMET H GEOMET σ_y F.B. Smith σ_z	GEOMET H GEOMET σ_y Pasquill-Dilution	GEOMET H GEOMET σ_y Wind Extrapolation	GEOMET H $\sigma_y = f w_A x$ Wind Extrapolation
Tower	0.41	0.26	0.41	0.41	0.41	0.26	0.38	0.31	0.46	0.49	0.47	0.51	0.48	0.47
Castle	0.75	0.75	0.75	0.75	0.75	0.75	0.66	0.75	0.75	0.66	0.63	0.66	0.69	0.72
Hockey	0.43	0.03	0.43	0.43	0.43	0.03	0.14	0.05	0.48	0.49	0.78	0.48	0.54	0.56
Munsey	0.51	0.18	0.51	0.51	0.51	0.18	0.38	0.32	0.55	0.61	0.44	0.59	0.62	0.63
Lambert	0.39	0.10	0.39	0.39	0.39	0.10	0.24	0.14	0.44	0.56	0.41	0.55	0.62	0.54
Johnson	0.34	0.07	0.34	0.34	0.34	0.08	0.12	0.09	0.35	0.38	[illegible]	0.37	0.38	0.38
Kents	0.29	0.21	0.29	0.29	0.29	0.21	0.29	0.23	0.32	0.35	0.34	0.35	0.38	0.36
Nashs	0.43	0.27	0.43	0.43	0.43	0.27	0.44	0.32	0.47	0.60	0.53	0.59	0.65	0.54

TABLE 68. RMSE OF MODEL TO MEASUREMENT COMPARISON FOR STABLE CONDITIONS

Station	Flat Terrain	CRSTER H	NOAA H	GEOMET H	VALLEY H	ERT-LAPPES H	ERT-LAPPES H GEOMET σ_y	ERT-LAPPES H LAPPES σ_y	GEOMET H LAPPES σ_y	GEOMET H GEOMET σ_y	GEOMET H GEOMET σ_y F.B. Smith σ_z	GEOMET H GEOMET σ_y Pasquill-Dilution	GEOMET H GEOMET σ_y Wind Extrapolation	GEOMET H $\sigma_y = f w_A x$ Wind Extrapolation
Tower	19.3	134.9	134.9	20.1	134.9	61.3	36.0	40.3	19.2	19.0	28.2	19.0	18.9	19.0
Castle	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	13.0	12.9	12.9	13.3
Hockey	13.0	443.6	443.6	45.5	429.7	65.4	38.9	42.5	30.9	28.4	47.8	41.1	19.8	22.2
Munsey	8.0	103.8	103.8	17.7	103.8	43.3	26.4	29.7	13.1	12.0	20.8	12.8	9.9	11.4
Lambert	4.6	62.6	62.6	15.7	62.6	38.0	48.4	45.3	14.4	14.5	33.7	17.1	9.3	6.6
Johnson	14.4	320.3	320.3	47.1	312.3	64.8	64.3	55.3	42.5	50.1	63.9	54.8	28.3	21.9
Kents	7.1	89.1	89.1	31.2	88.3	39.5	22.8	19.8	16.0	17.8	21.1	20.2	10.2	9.9
Nashs	5.4	23.6	23.6	9.3	23.6	23.0	15.0	16.4	7.9	7.4	11.5	7.8	6.1	6.6

TABLE 69. CORRELATION OF MODEL TO MEASUREMENT COMPARISONS FOR STABLE CONDITIONS

Station	Flat Terrain	CRSTER H	NOAA H	GEOMET H	VALLEY H	ERT-LAPPES H	ERT-LAPPES H GEOMET σ_y	ERT-LAPPES H LAPPES σ_y	GEOMET H LAPPES σ_z	GEOMET H GEOMET σ_z	GEOMET H GEOMET σ_y F.B. Smith σ_z	GEOMET H GEOMET σ_y Pasquill-Dilution	GEOMET H GEOMET σ_y Wind Extrap-olation	GEOMET H $\sigma_y = f\sigma_A^x$ Wind Extrap-olation
Tower	0.49	0.16	0.16	0.38	0.16	0.24	0.30	0.29	0.43	0.45	0.32	0.45	0.49	0.47
Castle	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.51	0.52	0.52	0.51
Hockey	0.52	0.02	0.02	0.06	0.02	0.05	0.08	0.07	0.09	0.11	0.07	0.08	0.17	0.13
Munsey	0.68	0.01	0.01	0.20	0.01	0.06	0.12	0.10	0.29	0.33	0.16	0.30	0.45	0.34
Lambert	0.66	0.05	0.05	0.22	0.05	0.08	0.06	0.06	0.23	0.23	0.09	0.19	0.35	0.49
Johnson	0.41	0.14	0.14	0.06	0.15	0.06	0.04	0.05	0.05	0.04	0.06	0.06	0.08	0.13
Kents	0.35	0.02	0.02	0.07	0.02	0.05	0.12	0.14	0.16	0.15	0.13	0.13	0.25	0.26
Washs	0.64	0.17	0.17	0.38	0.17	0.17	0.30	0.26	0.45	0.49	0.36	0.48	0.58	0.49

TABLE 70. NUMBER OF MODEL TO MEASUREMENT COMPARISONS

Station	Unstable	Neutral	Stable	All
Tower	476	899	2865	4240
Castle	73	611	1708	2392
Hockey	502	859	2834	4195
Munsey	506	932	2972	4410
Lambert	398	835	2544	3777
Johnson	452	730	2284	3466
Kents	499	924	2880	4303
Nashs	481	810	2692	3983

TABLE 71. COMPARISON OF HIGHEST AND SECOND HIGHEST 1-HOUR SO_2 CONCENTRATIONS BETWEEN MODELING TECHNIQUES

	Highest (ppb)					Second Highest (ppb)				
Station	Flat Terrain	CRSTER	GEOMET H GEOMET σ_y Wind Extrap.	GEOMET H $\sigma_y = f\sigma_A x$ Wind Extrap.	Meas.	Flat Terrain	CRSTER	GEOMET H GEOMET σ_y Wind Extrap.	GEOMET H $\sigma_y = f\sigma_A x$ Wind Extrap.	Meas.
Tower	1417	4187	1005	381	344	623	2780	476	368	317
Castle	479	479	355	99	268	276	276	114	84	260
Hockey	464	13804	463	585	318	411	11337	376	483	219
Munsey	599	3228	717	448	182	491	2706	397	383	178
Lambert	313	1820	265	223	77	311	1207	202	186	71
Johnson	1396	7532	1141	368	246	577	6062	981	339	199
Kents	123	4200	213	116	200	84	1049	120	111	180
Nashs	318	653	259	202	105	261	390	112	122	94

2. All concentrations greater than the mean plus one standard deviation for the hour were assumed to represent impact of the plume from the power plant. These values were therefore eliminated from further consideration in the background computation.

3. The mean of the remaining concentrations for each hour was computed and used as the background for that hour.

Hourly background concentrations ranged from 0 ppb to 74 ppb with a mean of 3 ppb.

The model to measurement comparisons presented in Tables 64 to 71 show the effects of adopting various changes to the basic flat terrain Gaussian plume model as it is represented by the PTMTP model. The results show the performance changes at different monitoring sites and for different stability conditions.

The flat terrain model run showed very large root-mean-square errors (RMSE) for unstable conditions (Table 64) with much smaller values for neutral (Table 66) and stable conditions (Table 68). For stable conditions the model showed linear correlation coefficients (Table 69) greater than 0.6 at the Munsey, Lambert and Nash's stations. Corresponding RMSEs for these three stations and for Kent's (Table 68) were the four lowest. Particularly poor correlation between measured and model estimated values occurred at Castlewood and Kent's for unstable conditions (Table 65), yet Castlewood showed the best correlation for neutral stability (Table 67). Looking at the correlation coefficients and the RMSE, the flat terrain model performed surprisingly well against the measured Clinch River data. However, the highest and second highest concentrations were overpredicted at all stations except Kent's. Dilution of the plume due to enhanced turbulence caused by the complex terrain may have produced actual concentrations much lower than the flat terrain model indicates. Also, the uncertainty in location of the plume is likely to have been greater at farther distances from the plant.

The plume height adjustments for elevated terrain resulted in very high concentrations, particularly at the stations substantially elevated above the plant. For example, use of the CRSTER plume height adjustment produced the following frequencies of estimated concentrations greater than or equal to 500 ppb:

Station	Cases
Tower	64
Hockey	50
Munsey	50
Johnson	21
Lambert	12
Kents	8
Nashs	1
Castlewood	0

Most of these high concentration estimates occurred with stable conditions. An analysis of the distribution of the arithmetic error for the CRSTER height adjustment run shows that for stable conditions the model overpredicted by more than 500 ppb with the following frequencies:

Station	Cases
Tower	27
Hockey	34
Munsey	12
Johnson	16
Lambert	9
Kents	7
Nashs	1
Castlewood	0

Slight improvement in the RMSE occurred with the NOAA height adjustment was used, but this model allows direct impact of the plume centerline on elevated terrain in stable conditions. Another slight improvement in RMSE occurred at three stations with the use of the VALLEY plume height adjustment which allows the plume to approach elevated terrain to within 10 m under stable conditions. Vast improvement in RMSE was shown with the use of the ERT-LAPPES adjustment which maintains the plume above the terrain at all times, but lowers the plume height above elevated terrain by various fractional amounts for unstable, neutral, and stable conditions. The best results were obtained with the GEOMET adjustment which makes no reduction of the plume height for neutral and unstable conditions and also does not allow the centerline to approach terrain to less than 40% of the initial plume height for stable conditions. The ERT-LAPPES plume height adjustment showed a significant improvement over the CRSTER, VALLEY, and NOAA adjustments for stable conditions, but the GEOMET adjustment proved to show an even greater reduction in the RMSE. The ERT-LAPPES height adjustment was only a very slight improvement over the CRSTER formulation for neutral and unstable conditions. The VALLEY, NOAA, and GEOMET plume height adjustment results are equivalent for neutral and unstable conditions since all three formulations do not alter the plume height for these conditions.

The GEOMET and ERT-LAPPES plume height adjustments were each utilized in conjunction with both the LAPPES and GEOMET σ_y enhancement factors. As mentioned, without σ_y adjustments, the model runs involving the GEOMET plume height adjustment showed lower RMSE values than those involving the ERT-LAPPES adjustment. Very little difference is apparent in comparing results of the LAPPES σ_y adjustment with the GEOMET σ_y modification over all stabilities. However, for neutral conditions the GEOMET σ_y adjustment had the highest correlation coefficient for all stations except Castlewood and showed significantly better correlations than with use of the LAPPES σ_y adjustment at Munsey, Lambert and Nash's.

Two additional modeling techniques (the F.B. Smith σ_z adjustment and the Pasquill initial dilution factor) did not produce any improvement over the combination of the GEOMET plume height adjustment and σ_y modifications. However, the use of the power law to extrapolate the Upper Hockey wind speed to plume height significantly improved both the correlations and RMSE.

Table 71 compares results for the two model adjustments which gave the best RMSE and correlation results with measured values, with the original model and with the original incorporating CRSTER plume height adjustment. The results are for the highest and second highest 1-hour SO_2 concentration at each of the 8 monitoring sites. It should be noted that the values are not paired values occurring for the same hours. They are the highest and second highest values over the data period.

Joint frequency tables of estimated concentrations versus measured concentrations were produced for each station and for each stability using the hourly output from one of the model runs which for convenience has been abbreviated to SSCTM for Single Source Complex Terrain Model. The model used for these comparisons includes the GEOMET H, GEOMET σ_y, and wind extrapolation adjustments. Seven categories of concentration were used:

Category	Concentration Range (ppb)
1	0-25
2	25-50
3	50-100
4	100-150
5	150-200
6	200-300
7	> 300

Tables 72 through 75 present these distributions for all stabilities combined. The major deficiency of the SSCTM model is the underprediction of SO_2 concentrations in the 25-50 ppb and 50-100 ppb ranges. This problem was very evident at all stations except Lambert and Kent's. It appears that overprediction was also rather common at several sites.

When results for all stabilities are reviewed (Table 62) the RMSE is lowest at 5 stations (i.e., Tower, Castle, Munsey, Lambert and Johnson) when the Pasquill σ_y is computed from σ_A (Table 64). The most substantial improvement occurred with unstable conditions where, for example, the RMSE at Castlewood was reduced by 19 ppb from the SSCTM run. Other significant RMSE reductions occurred at Tower, Munsey and Johnson. Table 71 indicates that the use of σ_A in predicting σ_y also results in the best prediction of the highest and second highest values. Very little change in RMSE and correlations were observed between the SSCTM with the GEOMET σ_y and with the use of σ_A for neutral and stable conditions. Johnson showed a significant improvement in RMSE for stable conditions and Lambert's correlation improved significantly for stable conditions also.

TABLE 72. JOINT FREQUENCIES OF SEVEN CLASSES OF SSCTM CALCULATED AND OBSERVED CONCENTRATIONS OF SO_2 AT TOWER AND CASTLE SITES

	Tower Observed						
Calculated	1	2	3	4	5	6	7
1	3553	292	182	44	13	4	0
2	23	30	27	9	3	3	0
3	18	7	1	3	0	0	0
4	5	1	6	1	0	0	0
5	2	0	6	0	0	0	0
6	1	1	0	1	0	0	0
7	3	1	1	0	0	0	0

	Castle Observed						
Calculated	1	2	3	4	5	6	7
1	2248	90	13	5	1	2	0
2	2	16	7	3	1	0	0
3	2	0	1	0	0	0	0
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	1	0	0	0	0	0	0

TABLE 73. JOINT FREQUENCIES OF SEVEN CLASSES OF SSCTM CALCULATED AND OBSERVED CONCENTRATIONS OF SO_2 AT LAMBERT AND JOHNSON SITES

	Lambert Observed						
Calculated	1	2	3	4	5	6	7
1	3651	35	4	0	0	0	0
2	51	9	2	0	0	0	0
3	15	1	1	0	0	0	0
4	5	1	0	0	0	0	0
5	1	0	0	0	0	0	0
6	1	0	0	0	0	0	0
7	0	0	0	0	0	0	0

	Johnson Observed						
Calculated	1	2	3	4	5	6	7
1	3205	115	56	8	2	0	0
2	32	14	1	0	1	0	0
3	8	2	1	1	0	0	0
4	5	2	1	0	0	0	0
5	3	0	0	0	0	0	0
6	6	0	0	0	0	0	0
7	3	0	0	0	0	0	0

TABLE 74. JOINT FREQUENCIES OF SEVEN CLASSES OF SSCTM CALCULATED AND OBSERVED CONCENTRATIONS OF SO_2 AT HOCKEY AND MUNSEY SITES

	Hockey Observed						
Calculated	1	2	3	4	5	6	7
1	3829	158	33	6	2	2	1
2	48	25	5	3	0	0	0
3	36	3	0	4	0	0	0
4	25	1	0	0	0	0	0
5	6	1	0	0	0	0	0
6	7	0	0	0	0	0	0
7	3	0	0	0	0	0	0

	Munsey Observed						
Calculated	1	2	3	4	5	6	7
1	4168	98	18	4	1	0	0
2	29	26	10	0	0	0	0
3	24	2	2	0	1	0	0
4	11	0	0	1	0	0	0
5	6	0	1	0	0	0	0
6	4	0	0	0	0	0	0
7	4	0	0	0	0	0	0

TABLE 75. JOINT FREQUENCIES OF SEVEN CLASSES OF SSCTM CALCULATED AND OBSERVED CONCENTRATIONS OF SO_2 AT KENTS AND NASHS SITES

	Kents Observed						
Calculated	1	2	3	4	5	6	7
1	4131	35	10	1	0	1	0
2	86	12	2	0	0	0	0
3	20	1	1	0	0	0	0
4	2	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0
7	0	0	0	0	0	0	0

	Nashs Observed						
Calculated	1	2	3	4	5	6	7
1	3853	43	6	1	0	0	0
2	40	16	10	0	0	0	0
3	8	2	2	0	0	0	0
4	1	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0
7	0	0	0	0	0	0	0

Cumulative frequency distributions of both the measured SO_2 concentrations and model predicted values were plotted on log probability paper for comparison. The graphs for the eight stations, showing the distribution results for the measured data along with those for three models, appear in Figures 109 to 116. Comparing the CRSTER, SSCTM, and Pasquill σ_A-GEOMET plume height results to the measured SO_2 data at Tower show that the CRSTER model most accurately predicted the lower concentration values, while the Pasquill σ_A-GEOMET plume height model performed the best at higher concentrations. An examination of the frequency distribution graphs for the other stations reveals a general pattern of the Pasquill σ_A model best representing the measured distribution at high concentrations, both the Pasquill σ_A and SSCTM models performing the best at moderate concentration levels, and only a small difference between models existing at low levels of SO_2. An exception to this pattern is the close match of the CRSTER distribution to the measured distribution at moderate SO_2 levels at Johnson.

The combination of Pasquill's method of estimating σ_y from σ_A and the GEOMET plume height adjustment produced the highest correlations and the lowest RMSE when the results were compared with the measured SO_2 data. In addition, this model also performed the best in predicting the highest and second highest concentrations. This model was therefore judged to have validated the best against the Clinch River data. However, for the purpose of common usage a model that requires σ_A as input is not practical since σ_A data are scarce and not normally observed at standard weather stations. When σ_A data are not available, other means of specifying dispersion parameters must be utilized. Therefore, the Single Source Complex Terrain Model (the combination of the GEOMET plume height and σ_y adjustments and wind extrapolation techniques), which performed almost as well as the Pasquill σ_A model, against the Clinch River data should be recommended for use. However, it has been demonstrated that this model shows an under-prediction of SO_2 concentrations in the 25-100 ppb range.

The remaining alternative for air quality prediction in complex terrain is the use of a numerical boundary layer flow model. Several such models were reviewed; the feature of these models that is most readily adaptable for inclusion in a Gaussian model is the use of a curvilinear plume trajectory. It has also been demonstrated at Clinch River that a curvilinear trajectory best matches the recorded plume position (at least within a few kilometers of the Plant) in the frequent high turbulence conditions associated with complex terrain (see Sections 7 and 8). For several hours during two days occurring during the July, 1977 helicopter monitoring period, curvilinear trajectories were produced using the method described in Section 7. Hand computations of SO_2 concentrations resulting from the use of curvilinear trajectories were performed using the Gaussian plume equation. Downwind and crosswind distances were determined by plotting the trajectories on maps. The resulting SO_2 predictions, along with the measured hourly average and peak SO_2 concentrations, are presented in Table 76. Improvement over the straight-line trajectory was found for hours 0900 EST of July 24 and

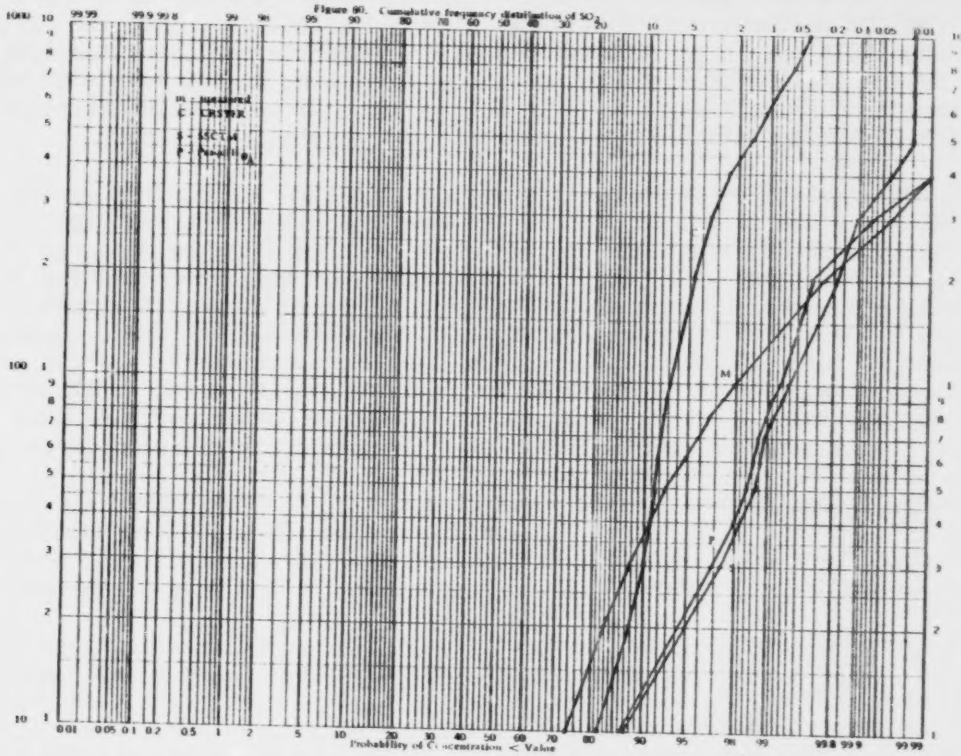


Figure 109. Cumulative frequency distribution of SO_2 for Tower.

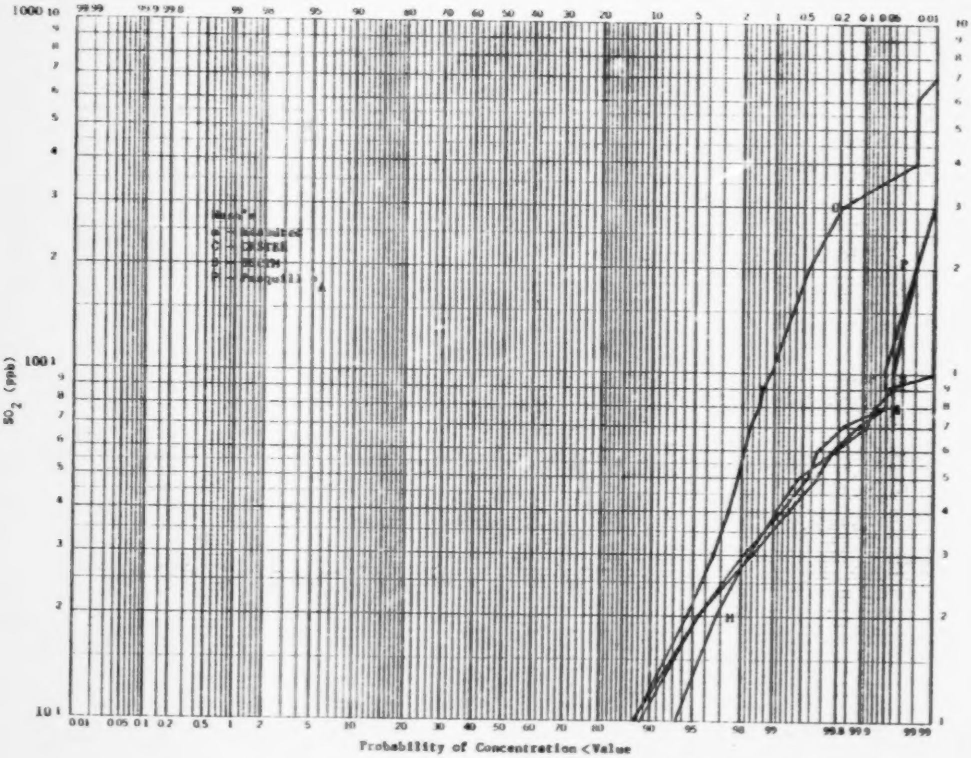


Figure 110. Cumulative frequency distribution of SO_2 for Nash's.

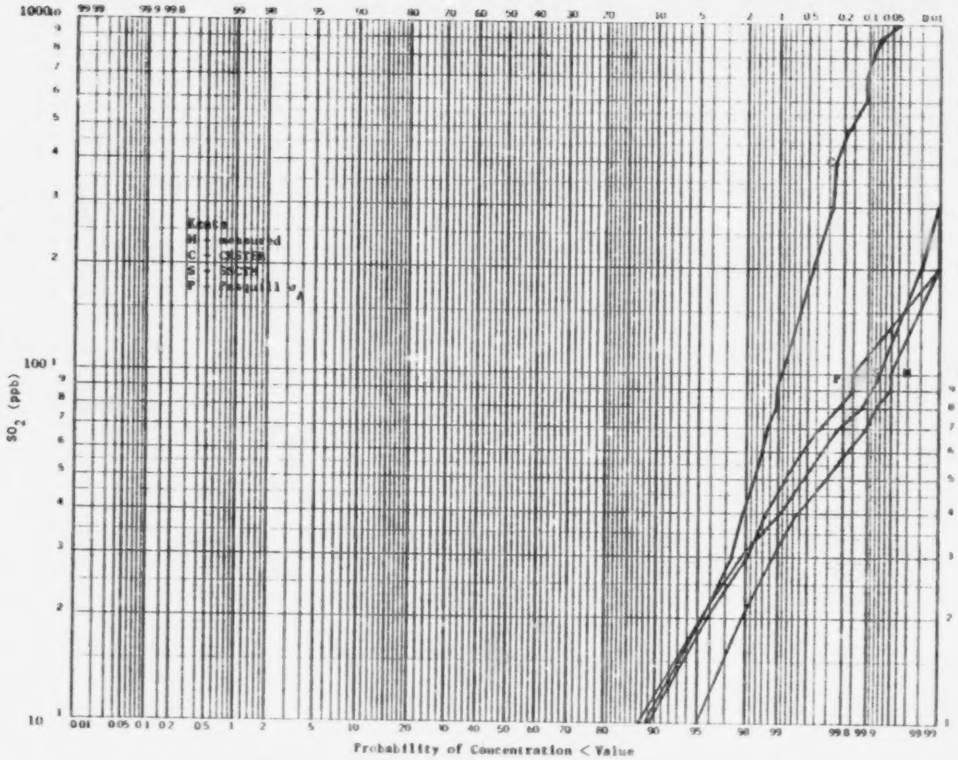


Figure 111. Cumulative frequency distribution of SO$_2$ for Keats.

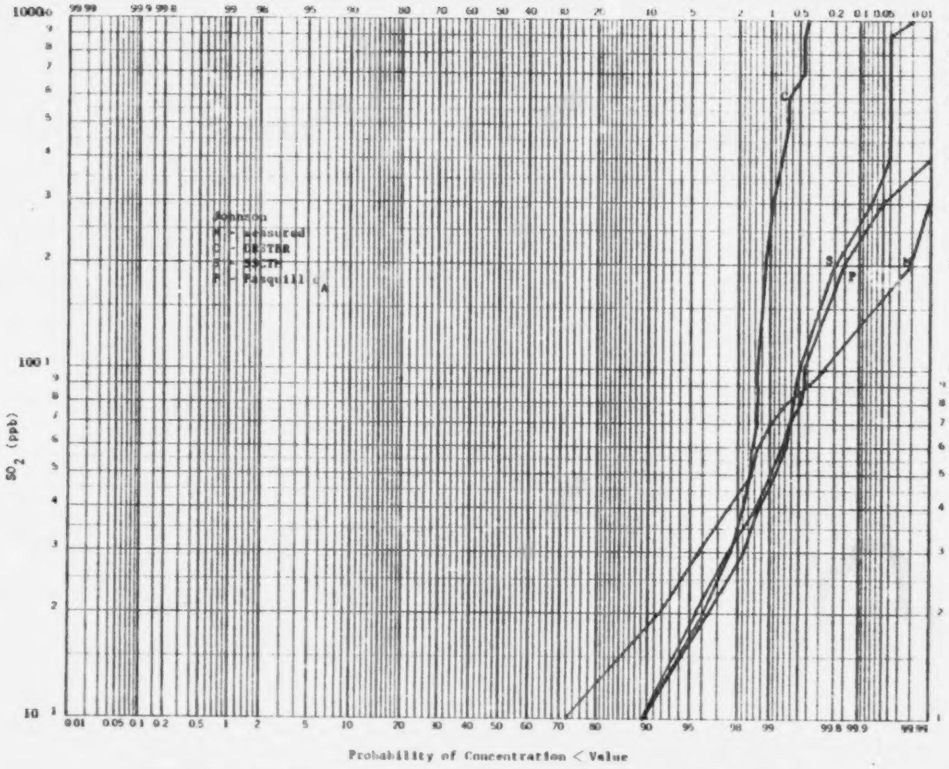


Figure 112. Cumulative frequency distribution of SO_2 for Johnson.

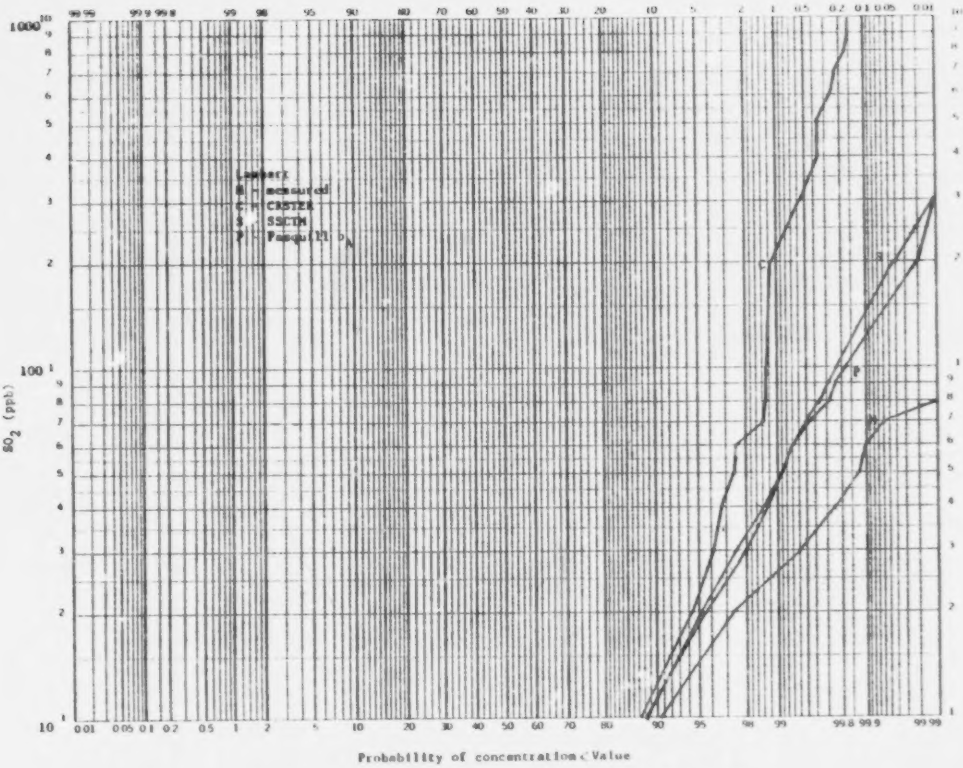


Figure 113. Cumulative frequency distribution of SO_2 for Lambert.

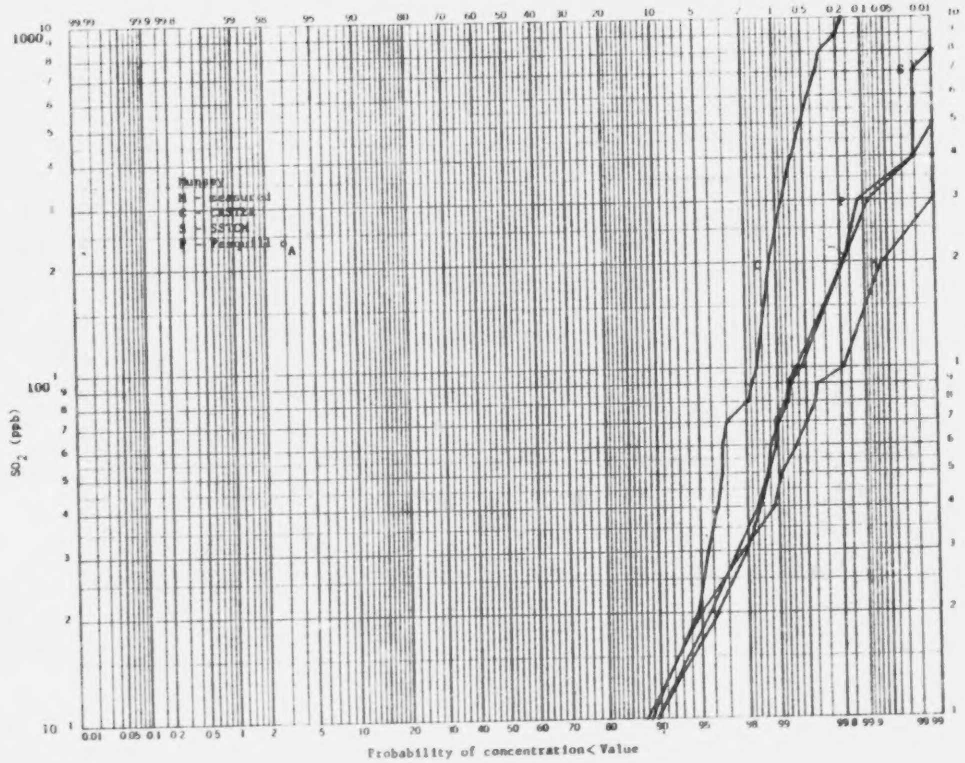


Figure 114. Cumulative frequency distribution of SO_2 for Monsey.

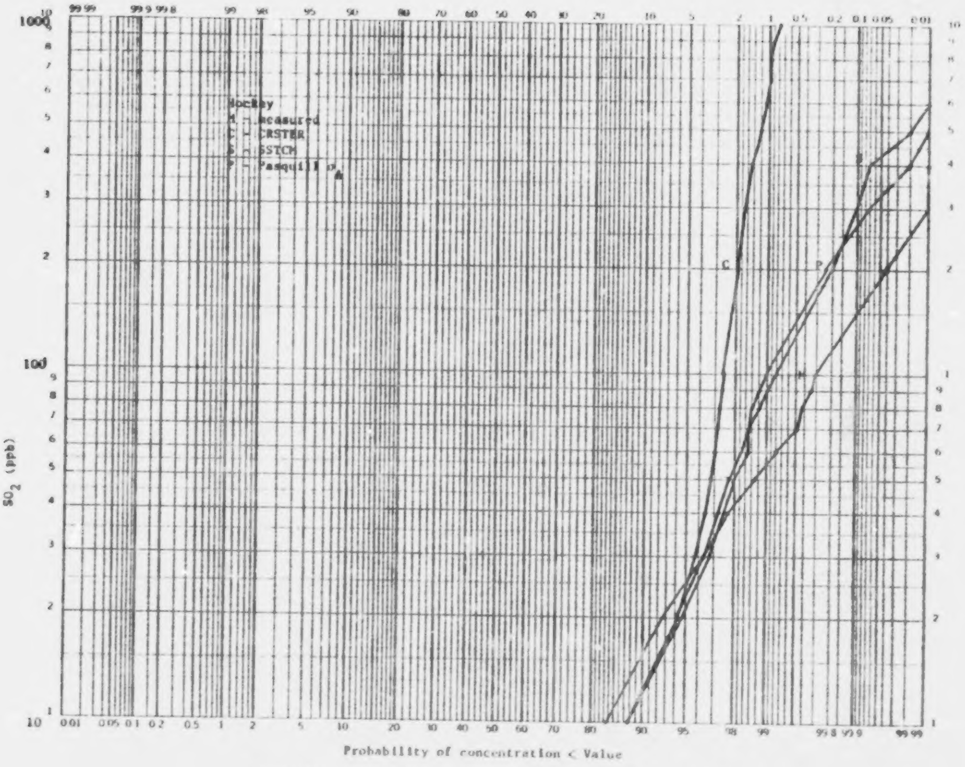


Figure 115. Cumulative frequency distribution of SO_2 for Hockey.

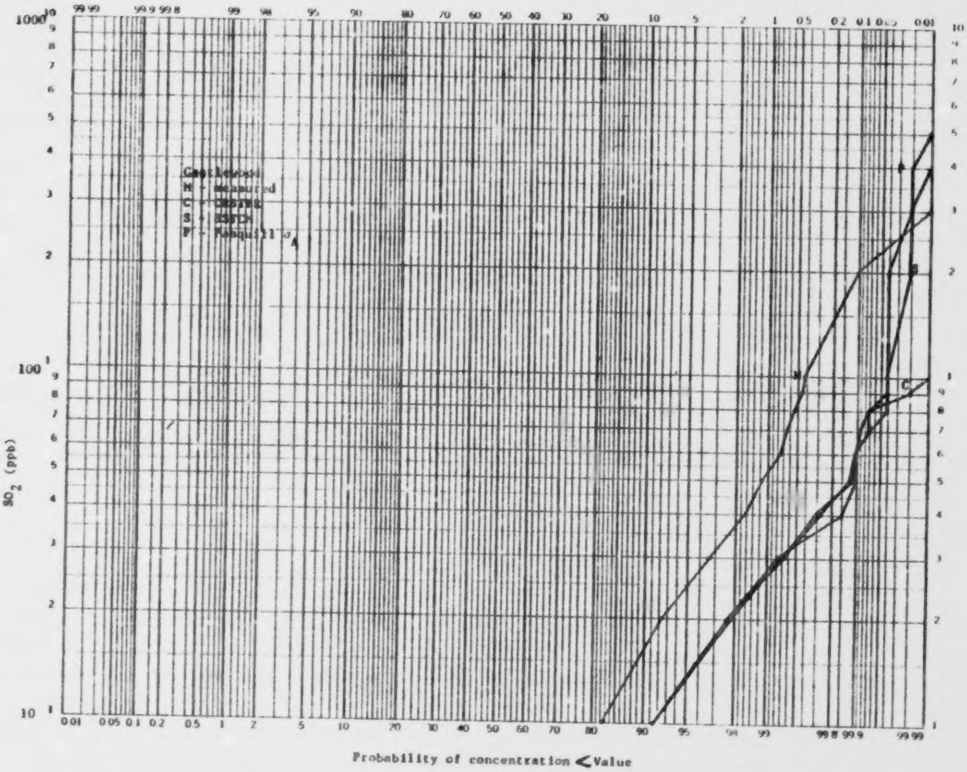


Figure 116. Cumulative frequency distribution of SO_2 for Cantlewood.

and for 1200 EST on July 26, but no general trend toward improvement in this small set of test cases was noted. Two alternatives may have potential for the improvement of model estimates: (1) use the trajectories produced for every two minutes to make a model calculation every two minutes, followed by averaging of these values for the hour; or (2) the computation of the average position of the plume during the hour using the individual two-minute trajectories followed by a single model calculation.

TABLE 76. COMPARISON OF LINEAR AND TRANSPORT CURVILINEAR MODELS

Date	Time	SO_2 (ppb) Linear	SO_2 (ppb) curvilinear	Measured SO_2 (ppb) hourly average/peak	Station
7/24/77	0800	0	0	31/135	Tower
	0900	0	9	31/85	Tower
	1000	154	225	38/175	Tower
	1100	39	1	73/165	Tower
	1200	39	57	21/85	Tower
	1300	184	390	15/34	Tower
7/26/77	1100	3	4	33/82	Johnson
	1200	9	54	45/82	Johnson

SUMMARY

The effectiveness of adjustments to the basic Gaussian plume model in improving its capability to estimate ground level concentrations in complex terrain was investigated. Thirteen modifications or combinations of modifications were introduced to the UNAMAP PTMTP program; including adjustments to treat the height of the plume above terrain (6 variations including the standard and 5 adjustments), the width (4 variations) and vertical thickness (3 variations) of the plume, and wind speed (2 variations). The model results were compared with measured values to determine correlation coefficients and root-mean-square-error (RMSE). Based on the model to measurement statistics, the highest calculated and measured values and plots of frequency distributions, the effectiveness of each model adjustment was determined at each of the eight monitoring sites, for unstable, neutral and stable conditions and for all stability conditions combined. The greatest improvement over the unadjusted flat terrain model occurred with the use of a moderate (60 percent of terrain rise) plume height reduction under stable conditions, plume width based on hourly wind direction fluctuations (σ_A) as proposed by Pasquill (1976) and wind speed extrapolated from near surface observations to plume height by a stability related power law function. Without wind direction fluctuation data the next best adjustment consisted of the same plume height and wind speed adjustments, but empirically increasing the Pasquill-Gifford plume width function (σ_y) by a factor of 2 for moderately unstable conditions and by a factor of 3 for neutral and stable conditions. These were the two best results of 13 adjustments evaluated. The evaluation presented here is by no means exhaustive of ways of adjusting the Gaussian plume model. One area of investigation which particularly needs to be pursued is the discrepancy between the hours of measured and calculated high SO_2 concentrations. Although we have shown that the frequency of occurrence of high values is reasonably well predicted over the course of a year, using the relationships we tested, the calculated and measured high values seldom occur during the same hour. There is a need to determine whether this is due to inadequate model inputs, such as wind direction, or whether there is a failure to represent the basic dispersion process; although both types of errors may occur, further investigation of the high value cases may identify which type of error is more improtant. A review of a few selected cases in Section 8.0 suggests that both types of situations occur. It appears that more detailed modeling approaches than the single empirically adjusted plume are required for a significant number of cases.

SECTION 11

APPLICATION OF DISPERSION MODEL AT ANOTHER LOCATION

Although the use of a model which employed measured σ_A data validated the best against the measured SO_2 data at Clinch River, Virginia, such a model cannot be used routinely due to a lack of standard σ_A observations at most locations. Therefore, for the purposes of testing a model at another site, the SSCTM without the use of σ_A values was chosen. This model utilizes the GEOMET plume height adjustment, the GEOMET σ_y adjustment and a wind extrapolation technique.

The region chosen for the test was the area surrounding the Homer City, Keystone, Seward and Conemaugh power plants in the vicinity of Johnstown, Pennsylvania. A network of 17 SO_2 monitoring stations exists in the vicinity of these plants. The major terrain features in the area are Chestnut Ridge and Laurel Ridge, both oriented in a southwest to northeast direction. Chestnut Ridge lies between the Homer City and the Conemaugh and Seward plants. Laurel Ridge is located to the southeast of all the plants (see Figure 117). Laurel Ridge extends as much as 500 m above the Homer City plant base. The terrain is generally hilly in all directions.

Table 77 summarizes the plant operating characteristics for each of the four plants. Hourly values of SO_2 emission rate and stack gas exit temperature and velocity were estimated from recorded hourly measurements of generator load.

SO_2 monitoring data for the year 1975 were available. Meteorological data for this same period were prepared for model input. Wind direction and speed were observed from the top of a 91 m tower located 10 km south of the Homer City plant. The elevation of the base of the tower is 244 m above plant base, putting the wind observation at 335 m above the plant base quite close to the normal plume height. As a result, the measured wind speed was taken as representative of wind speed at plume height and the wind extrapolation technique of the SSCTM was not employed.

Atmospheric stability was characterized as Pasquill Classes 1 to 6 using the vertical temperature gradient measured on the tower from 12 to 46 m. The following criteria were used (U.S. AEC, 1972):

Class	(°C/100 m)
A	< -1.9
B	-1.9 to -1.7
C	-1.7 to -1.5
D	-1.5 to -0.5
E	-0.5 to +1.5
F	> +1.5

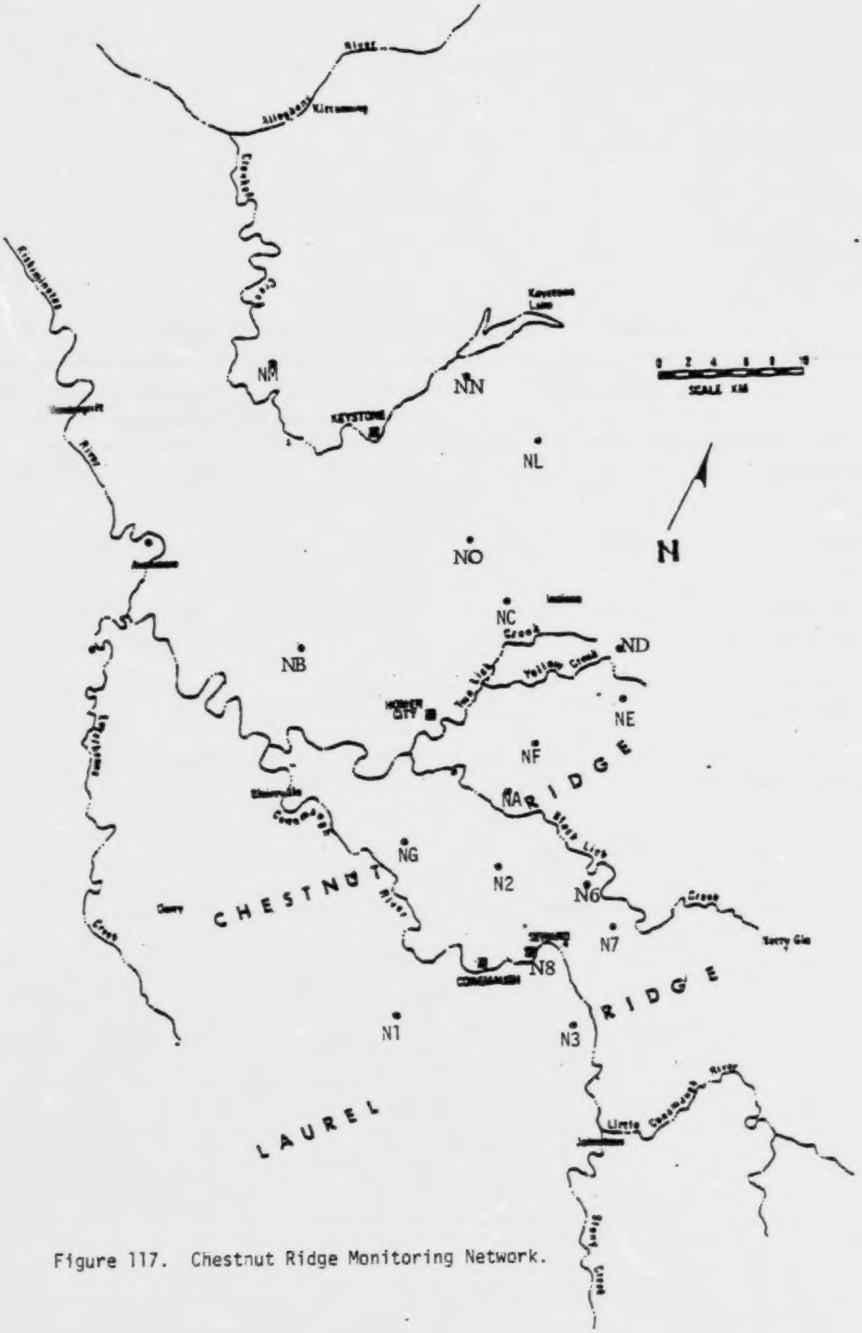

River
Allegheny
Kittanning
Keystone Lake
NM
NN
KEYSTONE
NL
SCALE KM
0 2 4 6 8 10
NO
N
Indiana
NC
Creek
ND
Yellow Creek
NB
HOMER CITY
NE
NF
NA
RIDGE
Lick
NG
N2
N6
CHESTNUT
River
Derry
Creek
N7
N8
CONEMAUGH
RIDGE
N1
N3
LAUREL
Little
River
Stony Creek

Figure 117. Chestnut Ridge Monitoring Network.

TABLE 77. PLANT OPERATING CHARACTERISTICS

	Homer City		Conemaugh	Keystone	Seward	
	1	2	1 & 2 identical	1 & 2 identical	1	2
Stack Height (m)	242.6	242.6	304.8	244.1	68.7	65.2
Diameter (m)	7.3	7.3	8.3	9.1	4.9	2.0
Exit Velocity (m/sec) 100% Load	23.7	23.7	23.1	21.3	13.7	23.4
Exit Temperature (°K) 100% Load	413	413	405	404	417	421
Typical SO_2 Emission Rate 100% Load (g/sec)	2043	2043	3499	3300	-	-
Generator Capacity MW 100% Load	600	600	890	850	135	90

Mixing heights were estimated from twice daily rawinsonde observations from Pittsburgh by the DeNardo and MacFarland Weather Service. These estimates were then interpolated to give hourly values. The interpolation is based on the following concept of diurnal mixing height variations. The mixing height rises from its early morning minimum to an afternoon maximum. The afternoon maximum remains constant but weakens during the evening. A new mixing height is formed under the weakening old height and becomes established by midnight at a height equal to the height indicated by the next morning's sounding. The interpolation procedure assigns the morning mixing height to the hours from 0000 EST to 0600 EST. The afternoon mixing height is assigned to 1400 through 2300 EST. The morning and afternoon mixing heights are linearly interpolated in time between 0600 and 1400 EST. Plume heights were estimated using the UNAMAP subroutine BEH072.

The same method of estimating background concentrations was employed for the Pennsylvania network as was used at Clinch River. The mean SO_2 background was much higher in the Chestnut Ridge area (17 ppb) compared with Clinch River (3 ppb).

A set of 8760 hourly concentration estimates of SO_2 were computed for each of the 17 monitoring stations. Each hourly concentration includes a contribution from each stack of each of the four plants lying within the Chestnut Ridge Monitoring Network. In addition a background concentration was added to the calculated plant contributions.

The results are presented in Table 78 as an analysis of the predictive ability of the model for the highest and second highest 1-hour average values over all stabilities. The highest and second highest values were overpredicted at 13 stations and underpredicted at 4 stations. Overpredictions were particularly evident at the two ridgetop stations (N3 and NG, Figure 117). Over the 17 stations the average model/observed ratio for the highest values was 1.23. It is concluded from the limited comparisons made with the central Pennsylvania data, that the model calculations compare more favorably with observed values than was the case with the Clinch River observations. The major shortcoming appears to be a tendency to overestimate concentrations on ridges. This result is found in the Clinch River data as well. It appears that more meteorologically comprehensive models which can more realistically represent flow over ridges will be required to obtain improved model performance.

TABLE 78. MODEL TO MEASUREMENT COMPARISONS OF 1-HOUR AVERAGES FOR CHESTNUT RIDGE - ALL CONDITIONS DURING 1975 (STATION LOCATIONS ARE SHOWN IN FIGURE 117)

	Highest (g/m^3)		Second Highest (g/m^3)	
Station	Observed	SSCTM	Observed	SSCTM
NA	787	1082	683	1080
NB	607	428	607	405
NC	524	572	439	485
ND	543	602	529	560
NE	612	803	484	771
NF	724	1015	710	911
NG	859	1845	649	1380
N1	987	724	798	676
NL	638	649	494	592
NM	508	777	407	667
NN	838	637	630	544
NO	535	636	489	607
N2	1181	1772	1048	1700
N3	1498	2585	1330	2528
N6	1064	1380	896	1252
N7	1812	1844	1601	1772
N8	2439	2318	2437	2296

REFERENCES

Briggs, G.A., 1969. Plume Rise, USAEC Critical Review Series, TID-25075, 82 pp.

Briggs, G.A., 1974. "Plume Rise from Multiple Sources," ATDL Contribution No. 91, Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, Tennessee.

Briggs, G.A., 1975. "Plume Rise Predictions," Proceedings of the AMS Workshop on Meteorology and Environmental Assessment," American Meteorological Society, 296 pp.

Burt, E.W., 1977. "VALLEY Model User's Guide," EPA Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, EPA-450/2-77-018.

Egan, B.A., 1975. "Turbulent Diffusion in Complex Terrain," Proceedings of the AMS Workshop on Meteorology and Environmental Assessment, American Meteorological Society, 296 pp.

Hanna, S.R., G.A. Briggs, J. Deardorff, B.A. Egan, F.A. Gifford and F. Pasquill, 1977. "AMS Workshop on Stability Classification Schemes and Sigma Curves -- Summary of Recommendations," Bulletin of the American Meteorological Society, 58, 1305-1309.

Holzworth, G.C., 1978. "Estimated Effective Chimney Heights Based on Rawinsonde Observations at Selected Sites in the United States," Journal of Applied Meteorology 17:153-60.

Irwin, J.S., 1979. "Estimating Plume Dispersion - A Recommended Generalized Scheme," Proceedings of the Fourth Symposium on Turbulence, Diffusion and Air Pollution of the American Meteorological Society, Reno, Nevada.

Koch, R.C., 1977. "A Study of Ambient SO_2 from Selected Non-Urban Pennsylvania Sources," GEOMET Report No. EF-583, Final Report to Pennsylvania Department of Natural Resources under Contract No. ME-75913, GEOMET, Incorporated, Gaithersburg, Maryland.

Koch, R.C., W.G. Biggs, P.H. Hwang, I. Leichter, K.E. Pickering, E.R. Sawdey and J.L. Swift, 1978. "Power Plant Stack Plumes in Complex Terrain, an Appraisal of Current Research," EPA-600/7-77-020, Contract No. 68-02-2260, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Koch, R.C., 1978. "Use of Monitoring Data to Modify Meteorological Dispersion Models for Point Sources," Presented at the 84th National Meeting of American Institute of Chemical Engineers, Atlanta, Georgia.

Koch, R.C., W.G. Biggs, D. Cover, H. Rector, P.F. Stenberg and K.E. Pickering, 1979. "Power Plant Stack Plumes in Complex Terrain, Description of an Aerometric Field Study," EPA-600/7-79-010a, Contract No. 68-02-2260, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Maxwell, C., 1979. Personal Communication.

Pasquill, F., 1976. *Atmospheric Dispersion Parameters in Gaussian Plume Modeling, Part II. Possible Requirements for Change in the Turner Workbook Values*. EPA Report Number EPA-600/4-76-030b, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Slowik, A.A., J.M. Austin, and G.N. Pica, 1977. "Plume Dispersion Modeling in Complex Terrain Under Stable Atmospheric Conditions," Presented at the 70th Annual Meeting of the Air Pollution Control Association, Toronto, Ontario.

Smith, F.B., 1972. "A Scheme for Estimating the Vertical Dispersion of a Plume from a Source Near Ground Level," Proceedings of the Third Meeting of the Expert Panel on Air Pollution Modeling, NATO/CCMS.

Thompson, R., 1979. "Dispersion of Sulfur Dioxide from the Clinch River Power Plant - A Wind Tunnel Study," Preliminary manuscript, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Turner, D.B., 1970. "Workbook for Atmospheric Dispersion Estimates," U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

U.S. Atomic Energy Commission, 1972. *Safety Guide 23*, Onsite Meteorological Programs, February 17, 1972.

U.S. Environmental Protection Agency, 1977. "User's Manual for the Single Source (CRSTER) Model," EPA Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, EPA-450/2-77-013.

Van der Hoven, I., G.J. Ferber, P.A. Humphrey, G.C. Holzworth, J.L. Heffter, and R.F. Quiring, 1972. "Southwest Energy Study Report of the Meteorology Work Group," NOAA.

Whaley, H., 1974. "The Derivation of Plume Dispersion Parameters from Measured Three-Dimensional Data," *Atmospheric Environment* 8:281-90.

APPENDIX A

FREQUENCY DISTRIBUTIONS AND MEAN CONCENTRATIONS OF MOBILE VAN DATA

Two-way classifications of pollutant concentrations, giving the mean concentration and frequency of occurrence of each table entry, are presented for the stationary samples taken by the mobile van. The tables are in the order listed below. All distances from the plant are in kilometers and all elevations are in feet above mean sea level.

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Page	Two-Way Classification
226	Distance versus elevation for SO_2
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228	Distance versus direction for SO_2
229	Distance versus elevation for NO_x
230	Hour versus elevation for NO_x
231	Distance versus direction for NO_x
232	Distance versus elevation for NO_2
233	Hour versus elevation for NO_2
234	Distance versus direction for NO_2
235	Distance versus elevation for NO
236	Hour versus elevation for NO
237	Distance versus direction for NO
238	Distance versus elevation for O_3
239	Hour versus elevation for O_3
240	Distance versus direction for O_3

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POLLUTANT: SO2

UNITS: PPB

DISTANCE FROM PLANT

ELEVATION	0.0- 0.5	0.5- 1.0	1.0- 2.0	2.0- 3.0	3.0- 5.0	5.0- 7.0	7.0-10.0	10.0-15.0	>15.0
0-1500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	45.96 (N = 9)	41.53 (N = 1)	0.00 (N = 0)	39.84 (N = 19)	0.00 (N = 0)	0.00 (N = 0)
1500-1600	123.93 (N = 36)	97.05 (N = 5)	19.29 (N = 11)	31.05 (N = 41)	49.56 (N = 76)	13.14 (N = 2)	25.38 (N = 7)	10.00 (N = 1)	0.00 (N = 0)
1600-1700	0.00 (N = 0)	0.00 (N = 0)	50.00 (N = 2)	8.53 (N = 11)	26.03 (N = 18)	34.40 (N = 13)	69.13 (N = 19)	56.22 (N = 11)	0.00 (N = 0)
1700-1900	0.00 (N = 0)	0.00 (N = 0)	22.50 (N = 4)	45.38 (N = 14)	41.66 (N = 221)	23.96 (N = 108)	21.64 (N = 31)	15.02 (N = 25)	0.00 (N = 0)
1900-2100	0.00 (N = 0)	0.00 (N = 0)	6.67 (N = 3)	1.00 (N = 5)	22.10 (N = 78)	26.65 (N = 49)	21.17 (N = 49)	29.76 (N = 48)	12.18 (N = 4)
2100-2300	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	20.00 (N = 1)	49.91 (N = 3)	20.31 (N = 15)	15.97 (N = 12)	3.92 (N = 9)	320.00 (N = 1)
2300-2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	40.88 (N = 26)	20.69 (N = 15)	11.75 (N = 1)	45.40 (N = 9)
> 2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	11.50 (N = 2)	26.14 (N = 6)	8.38 (N = 4)	8.20 (N = 5)

POLLUTANT: SO2

UNITS: PPB

HOUR

ELEVATION	0- 3	3- 6	6- 8	8-10	10-12	12-14	14-16	16-18	18-21	21-24
0-1500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	49.48 (N = 12)	23.31 (N = 7)	50.48 (N = 7)	33.94 (N = 3)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
1500-1600	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 1)	26.84 (N = 29)	74.04 (N = 59)	58.74 (N = 54)	86.90 (N = 24)	2.50 (N = 1)	0.28 (N = 5)	0.00 (N = 2)
1600-1700	0.00 (N = 0)	0.00 (N = 0)	38.47 (N = 4)	42.50 (N = 7)	36.18 (N = 17)	26.76 (N = 30)	88.69 (N = 13)	6.35 (N = 3)	0.00 (N = 0)	0.00 (N = 0)
1700-1900	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	30.42 (N = 41)	44.67 (N = 109)	37.59 (N = 155)	17.47 (N = 86)	10.09 (N = 12)	0.00 (N = 0)	0.00 (N = 0)
1900-2100	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 1)	15.19 (N = 13)	29.30 (N = 63)	24.23 (N = 99)	21.48 (N = 50)	6.19 (N = 7)	3.33 (N = 3)	0.00 (N = 0)
2100-2300	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 1)	10.34 (N = 12)	19.75 (N = 17)	56.75 (N = 8)	53.69 (N = 2)	0.00 (N = 1)	0.00 (N = 0)
2300-2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	35.29 (N = 4)	24.49 (N = 11)	51.81 (N = 10)	30.81 (N = 21)	43.63 (N = 5)	0.00 (N = 0)	0.00 (N = 0)
> 2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	7.74 (N = 5)	13.00 (N = 2)	16.11 (N = 5)	21.82 (N = 5)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)

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POLLUTANT: SO2

UNITS: PPB

DISTANCE FROM PLANT

DIRECTION	0.0- 0.5	0.5- 1.0	1.0- 2.0	2.0- 3.0	3.0- 5.0	5.0- 7.0	7.0-10.0	10.0-15.0	>15.0
0- 30	101.84 (N = 43)	0.00 (N = 1)	51.67 (N = 24)	7.69 (N = 13)	25.49 (N = 29)	18.29 (N = 12)	14.44 (N = 9)	26.68 (N = 11)	0.00 (N = 0)
30- 60	33.94 (N = 8)	149.74 (N = 3)	10.00 (N = 2)	85.00 (N = 4)	51.13 (N = 138)	38.06 (N = 52)	35.80 (N = 56)	27.16 (N = 71)	53.82 (N = 17)
60- 90	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	33.89 (N = 3)	52.76 (N = 70)	39.38 (N = 15)	28.33 (N = 47)	48.68 (N = 12)	12.70 (N = 5)
90-120	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 1)	31.16 (N = 28)	39.12 (N = 45)	13.30 (N = 9)	6.85 (N = 9)	10.00 (N = 1)
120-150	0.00 (N = 0)	36.00 (N = 1)	0.00 (N = 0)	104.50 (N = 4)	35.31 (N = 64)	12.97 (N = 15)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
150-180	0.00 (N = 0)	0.00 (N = 0)	160.00 (N = 1)	5.00 (N = 1)	39.10 (N = 23)	32.50 (N = 2)	25.66 (N = 11)	5.00 (N = 1)	0.00 (N = 0)
180-210	20.00 (N = 1)	140.00 (N = 2)	30.00 (N = 1)	0.00 (N = 0)	27.27 (N = 58)	32.18 (N = 18)	19.26 (N = 7)	10.00 (N = 1)	0.00 (N = 0)
210-240	0.00 (N = 0)	20.00 (N = 1)	7.50 (N = 2)	56.82 (N = 13)	0.00 (N = 0)	16.42 (N = 52)	33.53 (N = 32)	11.67 (N = 6)	0.00 (N = 0)
240-270	0.00 (N = 0)	70.00 (N = 1)	10.00 (N = 1)	9.38 (N = 10)	31.51 (N = 33)	22.50 (N = 2)	22.91 (N = 6)	0.00 (N = 0)	0.00 (N = 0)
270-300	0.00 (N = 0)	0.00 (N = 0)	60.00 (N = 1)	18.00 (N = 5)	30.00 (N = 4)	13.07 (N = 21)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
300-330	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	49.10 (N = 3)	41.60 (N = 7)	0.00 (N = 0)	17.37 (N = 5)	0.00 (N = 0)	0.00 (N = 0)
330-360	0.00 (N = 0)	0.00 (N = 0)	4.00 (N = 3)	31.65 (N = 37)	55.00 (N = 4)	20.00 (N = 1)	0.00 (N = 0)	0.11 (N = 3)	0.00 (N = 0)

POLLUTANT: NOX

UNITS: PPB

DISTANCE FROM PLANT

ELEVATION	0.0- 0.5	0.5- 1.0	1.0- 2.0	2.0- 3.0	3.0- 5.0	5.0- 7.0	7.0-10.0	10.0-15.0	>15.0
0-1500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	98.26 (N = 4)	29.59 (N = 1)	0.00 (N = 0)	102.49 (N = 24)	0.00 (N = 0)	0.00 (N = 0)
1500-1600	420.19 (N = 29)	300.94 (N = 7)	47.67 (N = 7)	56.03 (N = 50)	50.73 (N = 92)	4.11 (N = 1)	18.09 (N = 5)	95.47 (N = 4)	0.00 (N = 0)
1600-1700	0.00 (N = 0)	0.00 (N = 0)	155.00 (N = 2)	35.76 (N = 8)	47.97 (N = 19)	114.89 (N = 5)	56.62 (N = 25)	17.83 (N = 3)	0.00 (N = 0)
1700-1900	0.00 (N = 0)	0.00 (N = 0)	25.00 (N = 4)	73.82 (N = 15)	50.45 (N = 231)	44.43 (N = 118)	43.25 (N = 21)	39.18 (N = 10)	0.00 (N = 0)
1900-2100	0.00 (N = 0)	0.00 (N = 0)	23.33 (N = 3)	17.50 (N = 4)	37.77 (N = 92)	37.28 (N = 44)	32.35 (N = 49)	47.65 (N = 67)	7.24 (N = 3)
2100-2300	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	50.00 (N = 1)	26.53 (N = 16)	31.04 (N = 14)	35.26 (N = 16)	61.71 (N = 5)
2300-2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	29.84 (N = 38)	19.62 (N = 23)	8.06 (N = 1)	9.47 (N = 4)
> 2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 1)	21.59 (N = 6)	22.15 (N = 3)	10.15 (N = 9)

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POLLUTANT: NOX

UNITS: PPB

HOUR

ELEVATION	0- 3	3- 6	6- 8	8-10	10-12	12-14	14-16	16-18	18-21	21-24
0-1500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	129.81 (N = 16)	47.86 (N = 8)	98.26 (N = 4)	29.59 (N = 1)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
1500-1600	0.00 (N = 0)	0.00 (N = 0)	56.22 (N = 6)	53.14 (N = 38)	180.42 (N = 54)	95.98 (N = 53)	165.48 (N = 33)	0.00 (N = 0)	6.66 (N = 5)	10.19 (N = 2)
1600-1700	0.00 (N = 0)	0.00 (N = 0)	59.31 (N = 7)	76.07 (N = 7)	53.80 (N = 21)	59.25 (N = 17)	46.64 (N = 10)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
1700-1900	0.00 (N = 0)	0.00 (N = 0)	20.25 (N = 10)	56.94 (N = 64)	63.70 (N = 128)	38.63 (N = 149)	35.27 (N = 46)	11.93 (N = 2)	0.00 (N = 0)	0.00 (N = 0)
1900-2100	0.00 (N = 0)	0.00 (N = 0)	40.31 (N = 11)	40.00 (N = 28)	47.96 (N = 62)	34.73 (N = 101)	38.52 (N = 49)	8.97 (N = 7)	15.00 (N = 4)	0.00 (N = 0)
2100-2300	0.00 (N = 0)	0.00 (N = 0)	50.08 (N = 4)	47.32 (N = 5)	12.72 (N = 14)	42.90 (N = 20)	38.37 (N = 7)	0.00 (N = 0)	20.00 (N = 2)	0.00 (N = 0)
2300-2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	23.57 (N = 12)	20.99 (N = 16)	22.15 (N = 16)	29.93 (N = 22)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
> 2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	16.77 (N = 5)	11.62 (N = 6)	8.49 (N = 2)	13.36 (N = 5)	50.00 (N = 1)	0.00 (N = 0)	0.00 (N = 0)

POLLUTANT: NOX

UNITS: PPB

DISTANCE FROM PLANT

DIRECTION	0.0- 0.5	0.5- 1.0	1.0- 2.0	2.0- 3.0	3.0- 5.0	5.0- 7.0	7.0-10.0	10.0-15.0	>15.0
0- 30	438.79 (N = 27)	20.00 (N = 1)	68.37 (N = 10)	28.33 (N = 12)	48.51 (N = 23)	83.44 (N = 10)	21.71 (N = 12)	34.05 (N = 13)	0.00 (N = 0)
30- 60	92.59 (N = 6)	684.61 (N = 3)	0.00 (N = 1)	100.00 (N = 1)	69.30 (N = 131)	62.72 (N = 53)	43.00 (N = 56)	47.56 (N = 78)	24.80 (N = 17)
60- 90	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	149.11 (N = 1)	52.49 (N = 75)	27.54 (N = 18)	36.71 (N = 29)	55.43 (N = 8)	9.47 (N = 4)
90-120	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 1)	45.35 (N = 33)	35.58 (N = 38)	25.48 (N = 14)	24.45 (N = 2)	0.00 (N = 0)
120-150	0.00 (N = 0)	10.92 (N = 3)	0.00 (N = 0)	71.25 (N = 4)	20.53 (N = 69)	19.63 (N = 15)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
150-180	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	14.76 (N = 25)	0.00 (N = 0)	39.32 (N = 11)	0.00 (N = 0)	0.00 (N = 0)
180-210	0.00 (N = 0)	0.00 (N = 0)	50.00 (N = 1)	0.00 (N = 0)	47.92 (N = 31)	27.73 (N = 18)	18.92 (N = 3)	0.00 (N = 0)	0.00 (N = 0)
210-240	0.00 (N = 0)	0.00 (N = 0)	50.00 (N = 1)	98.26 (N = 4)	57.59 (N = 6)	33.86 (N = 37)	80.04 (N = 35)	0.00 (N = 0)	0.00 (N = 0)
240-270	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	38.01 (N = 7)	25.35 (N = 33)	32.88 (N = 4)	21.60 (N = 3)	0.00 (N = 0)	0.00 (N = 0)
270-300	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 2)	0.00 (N = 2)	29.69 (N = 27)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
300-330	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	174.10 (N = 3)	88.16 (N = 8)	11.39 (N = 3)	7.38 (N = 4)	0.00 (N = 0)	0.00 (N = 0)
330-360	0.00 (N = 0)	0.00 (N = 0)	10.00 (N = 3)	56.58 (N = 46)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	4.54 (N = 3)	0.00 (N = 0)

POLLUTANT: NO2

UNITS: PPB

DISTANCE FROM PLANT

ELEVATION	0.0- 0.5	0.5- 1.0	1.0- 2.0	2.0- 3.0	3.0- 5.0	5.0- 7.0	7.0-10.0	10.0-15.0	>15.0
0-1500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	36.97 (N = 4)	13.29 (N = 1)	0.00 (N = 0)	32.30 (N = 24)	0.00 (N = 0)	0.00 (N = 0)
1500-1600	72.65 (N = 25)	37.17 (N = 6)	47.83 (N = 1)	34.09 (N = 44)	20.38 (N = 85)	0.00 (N = 0)	25.73 (N = 3)	30.96 (N = 4)	0.00 (N = 0)
1600-1700	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	25.42 (N = 7)	31.58 (N = 17)	50.65 (N = 4)	21.57 (N = 16)	12.65 (N = 3)	0.00 (N = 0)
1700-1900	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	91.84 (N = 3)	25.12 (N = 221)	24.27 (N = 113)	30.19 (N = 20)	25.06 (N = 10)	0.00 (N = 0)
1900-2100	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	13.92 (N = 77)	18.68 (N = 35)	18.14 (N = 34)	25.54 (N = 62)	7.24 (N = 3)
2100-2300	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	13.78 (N = 15)	21.92 (N = 14)	27.71 (N = 14)	30.36 (N = 5)
2300-2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	16.13 (N = 32)	10.37 (N = 19)	3.19 (N = 1)	0.00 (N = 4)
> 2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	7.37 (N = 4)	22.15 (N = 3)	6.63 (N = 9)

POLLUTANT: NO2

UNITS: PPB

HOUR

ELEVATION	0- 3	3- 6	6- 8	8-10	10-12	12-14	14-16	16-18	18-21	21-24
0-1500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	38.34 (N = 16)	20.23 (N = 8)	36.97 (N = 4)	13.29 (N = 1)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
1500-1600	0.00 (N = 0)	0.00 (N = 0)	28.98 (N = 5)	26.99 (N = 38)	44.33 (N = 49)	28.64 (N = 42)	40.78 (N = 23)	0.00 (N = 0)	2.07 (N = 5)	2.79 (N = 2)
1600-1700	0.00 (N = 0)	0.00 (N = 0)	33.13 (N = 7)	34.85 (N = 7)	41.45 (N = 12)	19.13 (N = 13)	24.84 (N = 8)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
1700-1900	0.00 (N = 0)	0.00 (N = 0)	11.57 (N = 10)	25.35 (N = 64)	32.31 (N = 125)	22.02 (N = 133)	21.27 (N = 33)	8.09 (N = 2)	0.00 (N = 0)	0.00 (N = 0)
1900-2100	0.00 (N = 0)	0.00 (N = 0)	23.69 (N = 10)	20.98 (N = 24)	18.55 (N = 52)	17.79 (N = 81)	20.48 (N = 38)	3.76 (N = 6)	0.00 (N = 0)	0.00 (N = 0)
2100-2300	0.00 (N = 0)	0.00 (N = 0)	45.60 (N = 4)	42.10 (N = 5)	8.55 (N = 14)	22.44 (N = 19)	19.07 (N = 6)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
2300-2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	13.92 (N = 10)	9.84 (N = 13)	12.53 (N = 16)	14.63 (N = 17)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
> 2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	16.77 (N = 5)	6.92 (N = 6)	8.49 (N = 2)	4.40 (N = 3)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)

POLLUTANT: NO2

UNITS: PPB

DISTANCE FROM PLANT

DIRECTION	0.0- 0.5	0.5- 1.0	1.0- 2.0	2.0- 3.0	3.0- 5.0	5.0- 7.0	7.0-10.0	10.0-15.0	>15.0
0- 30	74.36 (N = 23)	0.00 (N = 0)	47.83 (N = 1)	0.00 (N = 0)	31.80 (N = 17)	73.65 (N = 6)	5.84 (N = 5)	36.49 (N = 9)	0.00 (N = 0)
30- 60	21.07 (N = 6)	67.09 (N = 3)	0.00 (N = 0)	0.00 (N = 0)	31.16 (N = 126)	32.22 (N = 48)	21.60 (N = 41)	25.91 (N = 75)	13.71 (N = 17)
60- 90	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	60.00 (N = 1)	21.76 (N = 72)	21.45 (N = 17)	20.67 (N = 22)	20.63 (N = 8)	0.00 (N = 4)
90-120	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	24.77 (N = 25)	16.62 (N = 29)	20.96 (N = 14)	1.60 (N = 2)	0.00 (N = 0)
120-150	0.00 (N = 0)	7.24 (N = 3)	0.00 (N = 0)	0.00 (N = 0)	11.17 (N = 66)	13.78 (N = 15)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
150-180	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	9.52 (N = 25)	0.00 (N = 0)	21.90 (N = 7)	0.00 (N = 0)	0.00 (N = 0)
180-210	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	21.51 (N = 28)	12.22 (N = 13)	8.56 (N = 3)	0.00 (N = 0)	0.00 (N = 0)
210-240	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	36.97 (N = 4)	25.34 (N = 6)	14.64 (N = 37)	29.40 (N = 35)	0.00 (N = 0)	0.00 (N = 0)
240-270	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	25.42 (N = 7)	14.32 (N = 33)	20.09 (N = 4)	16.94 (N = 3)	0.00 (N = 0)	0.00 (N = 0)
270-300	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	17.51 (N = 27)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
300-330	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	91.84 (N = 3)	16.70 (N = 3)	8.80 (N = 3)	7.37 (N = 4)	0.00 (N = 0)	0.00 (N = 0)
330-360	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	33.48 (N = 43)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	4.54 (N = 3)	0.00 (N = 0)

POLLUTANT: NO

UNITS: PPB

DISTANCE FROM PLANT

ELEVATION	0.0- 0.5	0.5- 1.0	1.0- 2.0	2.0- 3.0	3.0- 5.0	5.0- 7.0	7.0-10.0	10.0-15.0	>15.0
0-1500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	61.29 (N = 4)	16.29 (N = 1)	0.00 (N = 0)	70.38 (N = 24)	0.00 (N = 0)	0.00 (N = 0)
1500-1600	409.84 (N = 25)	310.77 (N = 6)	55.83 (N = 1)	25.71 (N = 44)	16.52 (N = 90)	0.00 (N = 0)	1.60 (N = 3)	64.51 (N = 4)	0.00 (N = 0)
1600-1700	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	14.46 (N = 7)	21.09 (N = 17)	80.47 (N = 4)	30.46 (N = 16)	5.18 (N = 3)	0.00 (N = 0)
1700-1900	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	82.26 (N = 3)	26.20 (N = 229)	21.05 (N = 113)	12.72 (N = 20)	16.62 (N = 10)	0.00 (N = 0)
1900-2100	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	19.54 (N = 77)	13.51 (N = 35)	19.29 (N = 37)	22.35 (N = 62)	0.00 (N = 3)
2100-2300	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	5.86 (N = 15)	9.16 (N = 14)	9.73 (N = 14)	31.35 (N = 5)
2300-2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	9.41 (N = 32)	8.85 (N = 19)	4.88 (N = 1)	18.69 (N = 4)
> 2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 4)	0.00 (N = 3)	3.55 (N = 9)

POLLUTANT: NO

UNITS: PPB

HOUR

ELEVATION	0- 3	3- 6	6- 8	8-10	10-12	12-14	14-16	16-18	18-21	21-24
0-1500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	91.53 (N = 16)	28.07 (N = 8)	61.29 (N = 4)	16.29 (N = 1)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
1500-1600	0.00 (N = 0)	0.00 (N = 0)	38.57 (N = 5)	24.77 (N = 41)	129.50 (N = 51)	70.85 (N = 42)	182.51 (N = 23)	0.00 (N = 0)	4.76 (N = 5)	7.41 (N = 2)
1600-1700	0.00 (N = 0)	0.00 (N = 0)	26.18 (N = 7)	41.22 (N = 7)	27.18 (N = 12)	20.68 (N = 13)	27.22 (N = 8)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
1700-1900	0.00 (N = 0)	0.00 (N = 0)	8.97 (N = 10)	31.84 (N = 64)	31.52 (N = 125)	17.81 (N = 136)	14.41 (N = 38)	3.84 (N = 2)	0.00 (N = 0)	0.00 (N = 0)
1900-2100	0.00 (N = 0)	0.00 (N = 0)	20.65 (N = 10)	23.92 (N = 26)	20.30 (N = 53)	16.80 (N = 81)	20.79 (N = 38)	3.63 (N = 6)	0.00 (N = 0)	0.00 (N = 0)
2100-2300	0.00 (N = 0)	0.00 (N = 0)	4.48 (N = 4)	5.22 (N = 5)	4.22 (N = 14)	15.89 (N = 19)	17.36 (N = 6)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
2300-2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	5.36 (N = 10)	5.74 (N = 13)	10.12 (N = 16)	15.21 (N = 17)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
> 2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 5)	4.71 (N = 6)	0.00 (N = 2)	1.24 (N = 3)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)

POLLUTANT: NO

UNITS: PPB

DISTANCE FROM PLANT

DIRECTION	0.0- 0.5	0.5- 1.0	1.0- 2.0	2.0- 3.0	3.0- 5.0	5.0- 7.0	7.0-10.0	10.0-15.0	>15.0
0- 30	427.82 (N = 23)	0.00 (N = 0)	55.83 (N = 1)	0.00 (N = 0)	21.12 (N = 17)	26.40 (N = 6)	12.25 (N = 5)	3.80 (N = 9)	0.00 (N = 0)
30- 60	71.52 (N = 6)	617.52 (N = 3)	0.00 (N = 0)	0.00 (N = 0)	36.28 (N = 136)	34.11 (N = 48)	20.04 (N = 44)	21.11 (N = 75)	11.10 (N = 17)
60- 90	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	89.11 (N = 1)	17.46 (N = 72)	4.77 (N = 17)	23.50 (N = 22)	34.81 (N = 8)	18.69 (N = 4)
90-120	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	27.14 (N = 25)	12.34 (N = 29)	4.57 (N = 14)	35.39 (N = 2)	0.00 (N = 0)
120-150	0.00 (N = 0)	4.01 (N = 3)	0.00 (N = 0)	0.00 (N = 0)	10.27 (N = 66)	5.86 (N = 15)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
150-180	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	6.53 (N = 25)	0.00 (N = 0)	14.18 (N = 7)	0.00 (N = 0)	0.00 (N = 0)
180-210	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	23.04 (N = 31)	9.06 (N = 13)	10.42 (N = 3)	0.00 (N = 0)	0.00 (N = 0)
210-240	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	61.29 (N = 4)	32.26 (N = 6)	19.60 (N = 37)	50.78 (N = 35)	0.00 (N = 0)	0.00 (N = 0)
240-270	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	14.46 (N = 7)	11.49 (N = 33)	12.80 (N = 4)	4.66 (N = 3)	0.00 (N = 0)	0.00 (N = 0)
270-300	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	12.36 (N = 27)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
300-330	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	82.26 (N = 3)	2.82 (N = 3)	3.93 (N = 3)	0.00 (N = 4)	0.00 (N = 0)	0.00 (N = 0)
330-360	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	24.24 (N = 43)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 3)	0.00 (N = 0)

POLLUTANT: O3

UNITS: PPB

DISTANCE FROM PLANT

ELEVATION	0.0- 0.5	0.5- 1.0	1.0- 2.0	2.0- 3.0	3.0- 5.0	5.0- 7.0	7.0-10.0	10.0-15.0	>15.0
0-1500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	4.32 (N = 9)	0.00 (N = 0)	0.00 (N = 0)	14.64 (N = 24)	0.00 (N = 0)	0.00 (N = 0)
1500-1600	33.99 (N = 29)	24.89 (N = 4)	21.90 (N = 5)	13.80 (N = 53)	20.46 (N = 101)	19.24 (N = 2)	15.17 (N = 5)	0.71 (N = 4)	0.00 (N = 0)
1600-1700	0.00 (N = 0)	0.00 (N = 0)	5.00 (N = 1)	0.91 (N = 6)	30.39 (N = 22)	4.59 (N = 5)	19.30 (N = 22)	9.65 (N = 3)	0.00 (N = 0)
1700-1900	0.00 (N = 0)	0.00 (N = 0)	14.00 (N = 2)	12.56 (N = 9)	19.51 (N = 232)	25.69 (N = 126)	22.96 (N = 26)	23.17 (N = 14)	0.00 (N = 0)
1900-2100	0.00 (N = 0)	0.00 (N = 0)	10.00 (N = 3)	5.75 (N = 4)	27.36 (N = 92)	34.54 (N = 47)	35.44 (N = 57)	29.72 (N = 63)	29.05 (N = 3)
2100-2300	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	37.58 (N = 10)	31.61 (N = 14)	35.53 (N = 11)	16.13 (N = 5)
2300-2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	25.14 (N = 45)	34.81 (N = 23)	33.75 (N = 1)	13.89 (N = 4)
> 2500	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	8.00 (N = 1)	32.85 (N = 4)	67.40 (N = 3)	20.60 (N = 9)

```
                                   POLLUTANT: O3

                                    UNITS: PPB


                                       HOUR

ELEVATION     0- 3        3- 6        6- 8        8-10       10-12       12-14       14-16       16-18       18-21       21-24
  0-1500      0.00        0.00        0.00       10.49       22.95        4.25        4.55        0.00        0.00        0.00
          (N =   0)  (N =   0)  (N =   0)  (N =  16)  (N =   8)  (N =   7)  (N =   2)  (N =   0)  (N =   0)  (N =   0)

1500-1600     0.00        0.00        5.00        9.89       12.01       24.30       30.24        6.92      102.88       27.30
          (N =   0)  (N =   0)  (N =   6)  (N =  39)  (N =  63)  (N =  53)  (N =  30)  (N =   1)  (N =   5)  (N =   2)

1600-1700     0.00        0.00        1.99       21.13       11.60       29.50       27.86        0.00        0.00        0.00
          (N =   0)  (N =   0)  (N =   7)  (N =   7)  (N =  18)  (N =  20)  (N =   7)  (N =   0)  (N =   0)  (N =   0)

1700-1900     0.00        0.00       14.46       13.39       19.30       25.67       24.94       23.05        0.00        0.00
          (N =   0)  (N =   0)  (N =  10)  (N =  58)  (N = 120)  (N = 140)  (N =  67)  (N =  14)  (N =   0)  (N =   0)

1900-2100     0.00        0.00       14.00       26.16       32.61       31.56       31.11       32.00       25.00        0.00
          (N =   0)  (N =   0)  (N =  11)  (N =  24)  (N =  54)  (N = 106)  (N =  62)  (N =   8)  (N =   4)  (N =   0)

2100-2300     0.00        0.00       10.36       10.79       48.48       30.41       29.04        0.00       32.50        0.00
          (N =   0)  (N =   0)  (N =   4)  (N =   5)  (N =  14)  (N =  11)  (N =   4)  (N =   0)  (N =   2)  (N =   0)

2300-2500     0.00        0.00        0.00       29.33       39.88       19.72       26.03       21.00        0.00        0.00
          (N =   0)  (N =   0)  (N =   0)  (N =  12)  (N =  16)  (N =  19)  (N =  22)  (N =   4)  (N =   0)  (N =   0)

 > 2500       0.00        0.00        0.00       46.65       18.07       32.41       30.13        0.00        0.00        0.00
          (N =   0)  (N =   0)  (N =   0)  (N =   5)  (N =   6)  (N =   2)  (N =   4)  (N =   0)  (N =   0)  (N =   0)
```

POLLUTANT: O3

UNITS: PPB

DISTANCE FROM PLANT

DIRECTION	0.0- 0.5	0.5- 1.0	1.0- 2.0	2.0- 3.0	3.0- 5.0	5.0- 7.0	7.0-10.0	10.0-15.0	>15.0
0- 30	36.33 (N = 27)	0.00 (N = 1)	20.75 (N = 6)	3.33 (N = 6)	26.00 (N = 23)	13.76 (N = 16)	20.00 (N = 11)	29.73 (N = 13)	0.00 (N = 0)
30- 60	26.49 (N = 6)	0.00 (N = 0)	20.00 (N = 1)	0.00 (N = 0)	10.65 (N = 112)	18.15 (N = 39)	23.35 (N = 54)	28.39 (N = 73)	20.78 (N = 17)
60- 90	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 1)	22.11 (N = 83)	24.16 (N = 19)	34.38 (N = 40)	8.19 (N = 8)	13.89 (N = 4)
90-120	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	8.00 (N = 1)	23.49 (N = 42)	38.70 (N = 42)	29.06 (N = 14)	32.17 (N = 2)	0.00 (N = 0)
120-150	0.00 (N = 0)	33.18 (N = 3)	0.00 (N = 0)	18.00 (N = 4)	31.65 (N = 58)	37.58 (N = 10)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
150-180	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	35.16 (N = 25)	0.00 (N = 0)	33.16 (N = 11)	0.00 (N = 0)	0.00 (N = 0)
180-210	0.00 (N = 0)	0.00 (N = 0)	8.00 (N = 1)	0.00 (N = 0)	16.03 (N = 55)	28.62 (N = 23)	44.43 (N = 3)	0.00 (N = 0)	0.00 (N = 0)
210-240	0.00 (N = 0)	0.00 (N = 0)	12.00 (N = 1)	4.32 (N = 9)	22.13 (N = 6)	28.69 (N = 51)	22.34 (N = 35)	0.00 (N = 0)	0.00 (N = 0)
240-270	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	1.09 (N = 5)	37.11 (N = 33)	9.56 (N = 4)	56.36 (N = 3)	0.00 (N = 0)	0.00 (N = 0)
270-300	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	20.00 (N = 2)	18.00 (N = 2)	32.06 (N = 27)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)
300-330	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	0.36 (N = 3)	21.95 (N = 8)	4.59 (N = 5)	32.85 (N = 4)	0.00 (N = 0)	0.00 (N = 0)
330-360	0.00 (N = 0)	0.00 (N = 0)	4.00 (N = 2)	14.53 (N = 50)	0.00 (N = 0)	0.00 (N = 0)	0.00 (N = 0)	88.83 (N = 3)	0.00 (N = 0)

APPENDIX B

FREQUENCY DISTRIBUTIONS
OF METEOROLOGICAL DATA

This appendix contains 2-way joint frequency distributions of meteorological variables observed at fixed monitoring sites. The following codes are used to represent meteorological measurements:

WD1 - Wind direction at 10 meters, deg.
WD3 - Wind direction at 30 meters, deg.
WS1 - Wind speed at 10 meters, m/sec
WS3 - Wind speed at 30 meters, m/sec
SG1 - Standard deviation of wind direction at 10 meters, deg.
SG3 - Standard deivation of wind direction at 30 meters, deg.
DT1 - Vertical temperature change from 0.5 to 4 m, °C
DT3 - Vertical temperature change from 0.5 to 30 m, °C
HOUR - Hour of the day representing ending of 1-hour average

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244	Hockey	WD1 (190 to 360) vs. HOUR
245	Hockey	WD3 (10 to 180) vs. HOUR
246	Hockey	WD3 (190 to 360) vs. HOUR
247	Lambert	WD1 (10 to 180) vs. HOUR
248	Lambert	WD1 (190 to 360) vs. HOUR
249	Tower	WD1 (10 to 180) vs. HOUR
250	Tower	WD1 (190 to 360) vs. HOUR
251	Tower	WD3 (10 to 180) vs. HOUR
252	Tower	WD3 (190 to 360) vs. HOUR
253	Munsey	WD1 (10 to 180) vs. HOUR
254	Munsey	WD1 (190 to 360) vs. HOUR
255	Castle	WD1 (10 to 180) vs. HOUR
256	Castle	WD1 (190 to 360) vs. HOUR
257	Nashs	WD1 (10 to 180) vs. HOUR
258	Nashs	WD1 (190 to 360) vs. HOUR
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260	Johnson	WD1 (190 to 360) vs. HOUR
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285	Tower	SE3 (3 to 48) vs. SG3

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                    HOCKEY  SITE

                 FREQUENCY DISTRIBUTION OF  WD1  VS HOUR          WD1  RANGE    0.000 TO  180.0

                                                                  ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                         W  D  1

               10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 TOTALS
       1.0       5     7     8     7     7     9     5     6     5    11     9     4     6     3     8    20    19    16    154
  H    2.0       7     4     4     9     4    12     4    11     6     7     7     6     3     1     6    11    23    25    150
       3.0       6     5     4     7     7     4     7     6     9     7    10     3     3     1     4    12    16    32    143
  O    4.0       6     6     6     2     5     7     7    11    12     8     8     1     2     3     4    10    20    28    146
       5.0      10     6     2     5     4     9     5     8    14    12     8     4     4     6     5     5    15    15    136
  U    6.0      11     7     4     3     6     7     5     7    13    14     7     7     3     1     5     6    13    23    142
       7.0       9     8     4     3     5     9     8     9    11     7    10     2     3     4     4    10     9    24    139
  R    8.0       9     1     2     2     7    10     5     6    13    10     8     8     3     2     2     3    10    19    120
       9.0      11     3     6     5     3     2     6     6    10    16     8     4     3     4     5     8     4    19    123
      10.0       9     8     5     4     1     3     1     6    10     8     3     7     4     1     4    11     6    10    101
      11.0      13    13     7     3     0     0     2     0     5     3     6     6     2     2     2     6     6     4     80
      12.0       6    12     8     1     1     2     2     1     3     4     4     0     3     5     0     3    12    12     79
      13.0      10     7     3     2     0     2     3     2     2     3     5     3     1     3     2     3     9    12     72
      14.0       5    10     6     2     1     2     0     1     2     5     6     2     1     8     2     5     7    15     80
      15.0       7     5     1     0     1     5     1     2     3     4     6     5     3     4     2     9     7    10     75
      16.0      12     9     1     0     1     0     2     0     6     3     6     3     0     1     2     9     6    10     71
      17.0      12     5     2     2     3     1     3     2     2     4     5     3     5     4     6     8     6     8     81
      18.0      14     8     3     1     2     1     0     2     4     3     6     7     1     1     4    11     6    12     86
      19.0      19     9     3     1     1     3     2     1     4     5     3     4     5     5    11    11    11    10    108
      20.0      21     4     6     2     3     1     6     3     4     6     4     6     7     6     9    13    13    19    133
      21.0      21    11     6     6     3     3     1     4     4     7     9    11     6    10     6    15    13    19    155
      22.0      12     7     9     7     5    11     2     5     9     5     9     5     6     3    14    16    29    14    168
      23.0       6     7     9    10     8     4     6     3     7     6     8     4     7     4     7    24    16    22    158
      24.0       7     9     7     4    14     6     1     6    11     8     5     4     4     6     9    16    19    24    160
    TOTALS     248   171   116    88    92   111    84   108   169   166   160   109    85    88   123   245   295   402

        0 WD1  VALUES LESS THAN   0.000          5869 WD1  VALUES LARGER THAN  180.0
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                    HOCKEY  SITE

                FREQUENCY DISTRIBUTION OF  WD1  VS HOUR          WD1  RANGE  180.001 TO  360.0

                                                                 ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                          W  D  1

            190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS
     1.0      23    21    19    19    11    15    13     4     4     3    11     9    13    11     5     4     8     6   200
H    2.0      29    21    30    13    14    12     5     7     4     7     8    11    11    11     8     6     9     3   209
     3.0      22    23    25    24     9    15    11    10     5     2     6     7    12     5     9     6    10     8   210
O    4.0      28    21    28    22    10    11     7    10     8     6     2    13    10    10     4     4     9     4   207
     5.0      19    34    34    22    20    15     9     5     2     3     3     7    16     7     2     1     6     5   211
U    6.0      25    33    28    23    13     8    12     9     5     6     7     8    11     3     2     4     5     4   206
     7.0      27    37    25    26    10     8     6     9     9     3     8    10     9     7     4     2     1     5   206
R    8.0      27    36    41    19    15    12     8    11     3     2     4     7     9     6     5     3     3     5   216
     9.0      28    38    49    23     8     8     8     7     7     5     3    11    15     4     4     2     6     6   232
    10.0      16    48    40    37    10     9    14    16     6     5     8     9    13     8     3     4     8    14   268
    11.0      23    30    50    22    18    23    10    18     9    13     9    10    14     8     5    10     8    11   291
    12.0      21    33    46    30    16    17    12    15    14     8    12    16    13     8     7     6    11    15   302
    13.0      25    30    50    31    16    16    19    14     9     9    10    17    10     7     5    10    14    17   309
    14.0      21    28    39    34    21    13    21    11    10     5     9    20    14    10     5    12    15    14   302
    15.0      15    36    44    29    20    11    13     9     9    10    11    17    12     7     6    13    15    22   299
    16.0      22    34    43    28    14    16    11    13    13     8    11    20    11     0     9     9    22    18   302
    17.0      19    33    36    23    12    20    12    13     5     9     7    17    12     6    17     7    31    17   296
    18.0      20    22    43    18    18    19     6     9     8     8     4    19    12     9     5    16    27    19   282
    19.0      33    15    29    24    15    11    12     5     8     2     7    16    17    12     5    16    28    12   267
    20.0      26    21    25    15    13    11    10     7     5     7    10    10    13    10     5    16    19    17   240
    21.0      20    17    22    19    12    12    12     7     5     5     7    12    16     9     6     8    13    10   212
    22.0      18    16    16    18    20    12     9     5     8     8     2    11    15    13     5    10     8     6,  200
    23.0      17    17    22    22    15    10    17     5     6     5    10    11    12     9     6     8     8     3   204
    24.0      16    20    14    17    22    12    16     5     4     5     9    10    13     8     6     8     5     7   197
  TOTALS     540   665   738   558   352   314   273   227   166   144   178   298   303   188   139   185   209   248

      2860 WD1  VALUES LESS THAN 180.001               0 WD1  VALUES LARGER THAN  360.0
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                 HOCKEY  SITE

            FREQUENCY DISTRIBUTION OF  WD3  VS HOUR          WD3  RANGE    0.000 TO  180.0

                                                              ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                           W  D  3

               10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 TOTALS
         1.0      3     6     6     7     5     5     7    10    10    11     4    18     4     3     4     5     8     5   121
   H     2.0      5     9     4     6     1     7    10    11     7    12     9     7     7     2     5     3     5     5   115
         3.0      9     3     5     5     6     9     5    10     7     6    11    10     2     4     2     2    10     4   110
   O     4.0      5     7     4     8     2     9     3    11     7     9    14    10     4     3     1     6     2    11   116
         5.0      3     6     7     6     0     9     5     7    10    12    11     5     8     5     2     2     5     8   111
   U     6.0      4     2    11     5     7     4     9     5    11     6    12     8     4     8     5     2     4     6   113
         7.0      3     6     6     6     7     9     5     8     6    12    12     7     6     6     3     3     7     6   118
   R     8.0      3     5     2     8     5     3     4    10     7    13    12    11     4     2     4     4     3     4   104
         9.0      5     5     5    11     5     5     5     2     7     9    13    11     3     2     2     3     8     6   107
        10.0      9     9     4     4     5     3     1     5     4     7    11     5     5     1     2     2     2     9    88
        11.0      8    10     8     7     4     6     0     1     1     3     3     8     2     3     1     1     3     7    76
        12.0      5     6    11     1     5     1     1     2     4     2     4     4     4     2     2     1     3     2    60
        13.0      9     9     7     5     2     0     1     2     0     5     4     7     0     1     2     2     1     5    62
        14.0      7     3     6     5     1     3     3     1     3     2     4     6     4     2     4     2     5     3    64
        15.0     10     3     1     2     3     3     1     2     3     4     3     2     4     5     2     3     5     8    64
        16.0      9     6     6     2     0     0     1     4     2     4     5     1     6     3     3     2     4     5    63
        17.0      4    12     4     3     3     1     1     4     0     2     5     3     4     6     1     5     4     6    68
        18.0     11     8     7     2     2     2     4     2     1     3     5     5     8     3     1     1     4     6    75
        19.0     15    10     6     6     4     0     1     2     2     9     4     7     4     5     1     2     9     9    96
        20.0     12    12    11     9     5     0     3     3     5     4     8     7     3     7     5     3    10     6   113
        21.0     17    11    10     7    10     1     6     5     8     7    10     7     9     9     5     5     7     6   140
        22.0      4    11     8     8     9     5     3     7     9    10    11     9    10     6     5     6     9    10   140
        23.0      8    10     3     8     9     5     4     7    12    14     7    10     9     3     6     2     7    13   137
        24.0      5     4    10     4    10     7     6    10     8     8     8    14     3     4     8     2     5    16   132
      TOTALS    173   173   152   145   110    97    89   131   134   174   190   182   117    95    76    69   130   166

           0 WD3  VALUES LESS THAN   0.000             5748 WD3  VALUES LARGER THAN  180.0
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                 HOCKEY  SITE

             FREQUENCY DISTRIBUTION OF  WD3  VS HOUR           WD3  RANGE  180.001 TO  360.0

                                                               ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                         W  D  3

             190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS
        1.0     11    24    22    23    21    23     9    12    11     5     7     7     8    16     8     7     6     6   226
 H      2.0     15    20    28    21    24    25    13     6    15     5     4     5     5    15     9     8     8     3   229
        3.0     15    13    24    29    30    18    16    13    12     9     5     2     6    10     8     8     9     5   232
 O      4.0     11    16    27    22    28    23    10    16     8    11     6     5     5    10    12     5     5     6   226
        5.0      8    13    18    27    36    27     8    11    12    11     6     1     9     7    14     5     7     5   225
 U      6.0      9    12    28    24    35    25    12    12     6     7     4     4     9     6    12     6     8     6   225
        7.0     11    14    24    27    34    22    14    15     8     6     5     5     4    13     6     9     5     4   226
 R      8.0     10    13    21    28    34    31    13    18     8     8     3     4     8    10     7     7     7     4   234
        9.0      3    12    17    31    42    26    13     9     8     6     7    11     6    11    10     6     9     4   230
       10.0      9     6    13    27    41    31     8     7    11    11     7    10    13    11    17     6     6     7   241
       11.0      4     5    13    21    47    24     7     8    12    10    14    15    14    18    14    11     9     7   253
       12.0      9    10    11    21    41    26     9    15     8    10    10    14    20    19    16    12    14    10   275
       13.0      5    12    13    16    44    21     9    12    15    12    12    10    16    24    16    10    10    14   271
       14.0      5     9     8    18    44    20    10    13    13     5    10     9    16    29    20    18     7    12   266
       15.0      9     4     5    13    50    19    12    11    14     9     4     6    23    27    16    17     7    20   266
       16.0      9     8     9    18    37    24    10    10    10    11     6    15    21    18    21    10    17    13   267
       17.0     10     4     6    21    40    18    10     8     7     8    11     9    19    21    29    16    12    17   266
       18.0      7    10    10    21    37    18    11     7     9     7     8     9     4    28    19    18    20    14   257
       19.0      9     7    20    16    30    16    14    10    10     7     6     2    13    28    13    14    15    17   247
       20.0      6    16    23    20    20    26     7     6     5     6     9     9     8    17    16    15    11    16   235
       21.0      8    14    20    19    20    19    12    11     5     3     6     5     6    25    16     7    10     6   212
       22.0     11    12    22    18    23    18    12    11     7     2     7     4     7    18    18     6     7     8   211
       23.0     11    17    17    16    30    18    14     7    11     3     8    10     6    14    14     5     7     4   212
       24.0      7    15    19    23    23    19    18    16    10     3     6     6    10    10    15     4     3     9   216
     TOTALS    212   286   418   520   811   537   271   263   235   175   170   177   256   405   346   230   219   217

        2393 WD3  VALUES LESS THAN 180.001              0 WD3  VALUES LARGER THAN  360.0
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                    LAMBER  SITE

           FREQUENCY DISTRIBUTION OF  WD1  VS HOUR          WD1  RANGE    0.000 TO  180.0

                                                            ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                              W  D  1

             10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 TOTALS
       1.0      2     6     3     4     4     9    24    15    11    10     3     3     5     1     0     3     3     4   110
 H     2.0     10     2     4     0     6    16    12    18    13     3     9     3     2     1     0     4     1     1   105
       3.0      3     6     1     5     3    10    13    21    16     8     3     1     2     3     2     2     3     0   102
 O     4.0      8     1     5     6     6     7    16    27    13    10     3     3     3     5     1     1     1     1   117
       5.0      4     3     3     7     7    11    20    15     8     4     6     0     4     5     4     3     2     0   106
 U     6.0      4     6     6     5     7    10    17    23    14     2     3     3     1     2     0     1     3     1   108
       7.0      3     4     7     6     7    16    14    21     4     4     4     6     1     1     1     2     1     2   104
 R     8.0      5     9     7    11    11    15     8    17     9     5     3     2     1     4     1     1     2     1   112
       9.0      2     2     5    12    11    14     7    11    10     6     6     3     1     1     0     0     2     0    93
      10.0      4     2     6    11     4    12     7     6     9     4     6     5     2     1     1     0     0     2    82
      11.0      4     5     0     3     5     3     9     5     8     6     7     4     1     3     2     0     0     1    66
      12.0      2     5     3     4     3     7     5     3     2     5     3     5     4     1     0     0     1     0    53
      13.0      5     8     4     2     6     3     3     4     1     1     2     2     5     3     2     1     1     0    53
      14.0      4     7     1     2     4     5     1     3     5     1     3     1     2     1     1     2     0     1    45
      15.0      4     3     8     3     2     0     1     3     2     3     4     2     2     1     0     2     2     1    43
      16.0      3     4     7     2     3     1     0     4     2     3     1     1     3     0     2     0     0     0    36
      17.0      2     6    10     3     3     5     2     1     3     0     3     1     2     1     0     0     0     1    43
      18.0     10     1     3     1     4     3     3     2     3     4     2     0     2     3     0     0     2     2    48
      19.0      7     5     4     3     7     3     3     0     4     2     3     2     3     4     1     0     0     3    54
      20.0      4     3     2     2     6     8     4     3     7     6     2     1     2     6     1     2     4     4    67
      21.0      6     3     3     5     3     5     7     6     5     6     6     2     6     3     7     2     7     3    85
      22.0      6     3     6     6     9     9     9    10    10     4     5     3     0     3     1     1     5     1    91
      23.0      4     4     7     5     9     9     8    15    14     7     6     1     4     1     1     2     2     1   100
      24.0      6     2     0     3     6    15    16    16     6     7     6     4     4     2     1     2     2     1    99
    TOTALS    112   103    99   111   136   197   209   249   179   111    99    64    62    54    29    31    41    31

        0 WD1  VALUES LESS THAN   0.000          3493 WD1  VALUES LARGER THAN  180.0
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                       LAMBER  SITE

                  FREQUENCY DISTRIBUTION OF  WD1  VS HOUR          WD1  RANGE  180.001 TO  360.0

                                                                   ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                            W  D  1

               190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS
       1.0        3     1     3     1     5    10    13    18    18     6     8     3     4     8     4     4     5     5   119
  H    2.0        1     1     7     3     9     5    12    21    13    12     9     3     4     4     9     3     5     3   124
       3.0        1     2     1     7     8     9    11    14    20    11     6     6     6     6     6     3     5     5   127
  O    4.0        1     2     3     3     6    12    11    12    15     8     9     6     5     3     4     2     7     4   113
       5.0        2     2     2     2     5    16    14    18    10     7     7     6     8     8     3     2     5     2   119
  U    6.0        1     1     3     3     4     5    24    19    14    11     5     2     5     3     4     3     4     5   116
       7.0        1     3     2     2     2     8    22    16    19    10     7     0     8     4     3     2     4     8   120
  R    8.0        3     1     3     0     1    10    11    16    20    16     4     9     3     5     4     2     5     2   115
       9.0        2     2     0     1     7     8    15    18    21    18     6     6     8     4     2     3     5     3   129
      10.0        1     1     0     1     6     6    11    30    23    18     8     6     6     5     2     5     4     8   141
      11.0        0     0     3     2     2     7    18    26    38    18    10     6     5     4     4     2     5     6   156
      12.0        0     2     0     1     3    11    18    44    27    19    11     7     9     3     4     6     4     3   172
      13.0        0     1     1     1     3    11    14    47    29    13    10     8    13     3     6     3     5     3   171
      14.0        2     2     1     2     4    12    20    33    28    17     8    10    11     6     8     5     3     7   179
      15.0        4     3     3     2     0     4    20    48    29    15     9     9     9     4     6     5     6     4   180
      16.0        2     3     2     4     3    10    22    46    25    14    12    11     9     4     5     9     7     3   191
      17.0        2     2     5     3     4    17    24    29    22    13     6    13     9    11     1     7    10     3   181
      18.0        1     2     3     5     8    22    27    16    13    11    10    18    11     3     6     7     3     6   172
      19.0        4     3     4    10    14    16    21    19    20     8    14     7     9     4     4    10     6     1   174
      20.0        3     7     7     5    16    19    22    19    17     3     8     7     6     8     2     3     5     2   159
      21.0        2     2     3     9    10    17    17    18    19    10     6    11     8     3     2     0     2     4   143
      22.0        1     2     2     1    11    16    11    15    21    11    12     8     9     5     2     2     4     4   137
      23.0        1     3     1     5     5    11    16    17    21     6    11     5     8     3     4     0     5     4   126
      24.0        4     5     3     1     3    15    13    25    20     6     6     6     6     7     1     2     4     2   129
    TOTALS       43    53    62    74   139   276   407   584   531   281   202   173   179   118    96    90   118    97

        1922 WD1  VALUES LESS THAN 180.001              0 WD1  VALUES LARGER THAN  360.0
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                     TOWER   SITE

               FREQUENCY DISTRIBUTION OF  WD1  VS HOUR          WD1  RANGE    0.000 TO  180.0

                                                                ROW * COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                              W  D  1

              10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 TOTALS
       1.0       1     4     2     4     9    11    20    14     5     3     3     1     2     0     0     1     3     3    86
   H   2.0       5     2     3     4     4     9    24    11     6     2     2     2     1     0     3     0     3     3    84
       3.0       2     1     4     2     5    21    20    16     8     5     5     1     1     0     2     2     4     1   100
   O   4.0       4     2     5     7     9     7    31    19    10     7     3     1     2     0     3     0     3     1   114
       5.0       1     3     7     5     5    13    21    31    11     1     1     4     0     0     1     1     0     1   106
   U   6.0       2     0     5     4     5    17    33    30     7     7     1     1     1     2     0     1     1     1   118
       7.0       1     1     6     4     6    12    24    34    15     7     1     1     1     0     4     0     2     2   121
   R   8.0       3     3     4     5     7     8    19    25    26    14     5     3     3     0     1     2     2     0   130
       9.0       1     1     3     4    10     9     9    24    28    22    10     2     4     4     2     1     1     1   136
      10.0       2     7     6     4     7     5     4    18    19    22    12     5     5     0     0     1     1     3   121
      11.0       3     5     6     5     7     6     7     7     9    11     8     2     1     1     3     1     1     1    84
      12.0       3     6     6     5     6     4     3    10     5    10     5     2     1     0     3     1     1     4    75
      13.0       9     8     5     5     5     4     5     3     4     8     2     5     4     4     2     0     2     2    77
      14.0       8     3     3     5     1     2     6     6     2     4     2     5     4     2     5     1     4     4    67
      15.0       8     5     6     4     3     3     3     9     6     5     5     5     3     3     2     3     2     1    75
      16.0       7     6     3     7     5     5     1     7     8     2     1     8     4     2     2     1     3     4    76
      17.0      12    12    12     5     3     3     3     8     5     3     7     3     1     1     2     2     5     4    91
      18.0      10     7    10     9     3     3     3     8     6     5     1     7     3     2     2     2     1     2    84
      19.0      14    10     8    10     4     3     4     5     6     8     2     3     2     4     2     5     5     1    96
      20.0      14    10     8     4     5     4     5     9     6     2.    6     6     2     3     5     2     3     4    98
      21.0       8     4     6     5     8     8     9    10     2     5     8     5     3     1     1     3     2     2    90
      22.0       4     2     3     3    10    11    10    11     8     3     3     6     2     0     0     5     2     1    84
      23.0       3     1     5     4     7     6    14    12     4     4     5     0     1     2     0     0     2     2    72
      24.0       5     4     2     2    12    10    10    14     6     5     2     4     1     3     2     1     1     2    86
    TOTALS     130   107   128   116   146   194   288   340   212   165   100    82    52    34    47    36    54    50

         0 WD1  VALUES LESS THAN   0.000          4737 WD1  VALUES LARGER THAN  180.0
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                 TOWER   SITE

               FREQUENCY DISTRIBUTION OF  WD1  VS HOUR          WD1  RANGE  180.001 TO  360.0

                                                                ROW * COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                        W  D  1

            190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS
       1.0      2     0     2     4    10     8    21    19    21    18    11    10    14    17     9    10    10     7   193
 H     2.0      0     3     1     6     4     8    17    11    15     8    11     7    13    16    10     6     8     2   146
       3.0      0     0     7     5     5    15    10    21    19    12    13     8    12    11    15     7    11     0   171
 O     4.0      1     2     4     4     7     5    17    17    10    16     9    12     7    13    13     4     4     4   149
       5.0      1     2     1     2     5    12     8    19    17    14    12    12    11     6    11     6     0     3   142
 U     6.0      2     2     0     3     7     9    20    17    10    18     7     9     6     6    10     4     6     3   139
       7.0      0     1     1     4     4    10    19    15    14    14    11     7     8    10     8     3     2     1   132
 R     8.0      1     2     1     2     7    13    19    20    23    14     5     5     6     5     3     3     4     0   133
       9.0      4     1     0     6     6    19    23    24    29     9    10     5     5     2     5     1     4     2   155
      10.0      1     0     5     3    14    17    18    25    36    19     9     7     3     2     4     5     1     2   172
      11.0      1     5     8    17    18    19    30    23    35    16    13    12     3     6     2     2     2     2   214
      12.0      1     6     5    11    18    34    21    27    31    17    14    12    10     2     3     8     3     6   229
      13.0      5     5     7    11    20    36    20    28    19    17    17    12     8     6     6     6     5     4   232
      14.0      3     4     8     8    19    28    28    22    23    23    18    16     4     6     6     7    10     5   238
      15.0      4     3     6     6    31    25    28    19    23    19    17    13     6     6     8     9     3     6   232
      16.0      2     6     7    10    21    38    23    20    20    22    14    15     9     7     3     4    11     9   241
      17.0      2     4     2     9    18    23    24    34    18    17    17    16     4     7     4     6     8    13   226
      18.0      4     6     7     7    27    25    20    24    24    13    20    13     9     7     7     5    12     8   238
      19.0      5     7    10    16    17    12    17    26    18    23    14    16     9     7     5     8    12    11   233
      20.0      2     8     9     8    11     9    28    21    24    21    19    17    15    15     9     9     8     6   239
      21.0      1     6     8     5    14    13    15    16    18    17    18    14    20    15    20    12     9     2   223
      22.0      1     5     3     6    12    19    19    13    16    19    14    14    23    26    15    14     7     5   230
      23.0      1     1     6     4    10    13    18    21    17    13    16    20    15    30    20    11     9     6   231
      24.0      0     2     3     2    13    17    13    21    15    10    23    10    27    12    15     4     7     5   199
    TOTALS     44    81   111   159   318   427   476   504   495   388   332   282   247   240   211   154   156   112

       2271 WD1  VALUES LESS THAN 180.001                 0 WD1  VALUES LARGER THAN  360.0
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                    TOWER   SITE
                 FREQUENCY DISTRIBUTION OF  WD3  VS HOUR           WD3  RANGE    0.000 TO  180.0
                                                                   ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS
                         W  D  3
              10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 TOTALS
      1.0      3     3     5     7     5    12    19     7     6     5     4     1     0     2     1     1     5     3    89
 H    2.0      1     2     3     1     6    16    12     6     5     4     2     0     1     2     2     3     0     4    70
      3.0      1     4     0     3    11    15    15    14     4     2     2     4     1     0     2     3     3     1    85
 O    4.0      5     1     4     7     3    17    18    12     9     3     3     2     2     1     2     1     3     1    94
      5.0      2     3     2     2     6    12    26    15     6     3     2     3     0     1     0     1     1     2    87
 U    6.0      0     1     1     2     8    24    21    13     3     3     5     2     4     2     1     0     1     2    93
      7.0      0     2     3     3     2    19    25    13     5     3     2     4     2     3     2     3     3     1    95
 R    8.0      3     3     1     4     2    19    22    18    10     6     2     2     5     2     1     1     2     2   104
      9.0      0     2     2     4     1     8    20    15    21     6     4     5     2     4     2     2     2     1   101
     10.0      2     1     4     4     3     3    14    14    23     4     9     3     4     5     0     1     3     2    99
     11.0      2     3     4     1     2     4     9     9    13     8     7     2     4     2     0     1     1     1    73
     12.0      8     3     2     2     3     2     7     4     8     5     2     3     3     4     5     2     0     2    65
     13.0      6     1     3     5     5     0     6     3     4     2     5     4     6     2     1     0     5     3    61
     14.0      1     3     1     3     1     3     7     3     3     5     0     7     4     3     2     6     6     2    60
     15.0      2     3     4     3     2     0     1     5    11     5     2     5     4     4     4     3     2     2    62
     16.0      6     5     5     2     2     1     2     6     7     1     3     6     4     4     3     2     4     4    67
     17.0      9     5     0     2     3     2     6     5     3     4     2     3     2     3     2     7     5     1    64
     18.0      5     7     5     6     1     2     4     6     2     4     2     6     1     2     3     2     2     2    62
     19.0      5     6     9     3     3     4     2     2     4     3     3     4     1     5     0     3     4     2    63
     20.0      8    10     3     2     6     4     2     3     6     3     7     4     2     1     3     4     4     5    77
     21.0      2     6     7     3     4     7     9     6     7     3     5     4     6     1     2     4     3     4    83
     22.0      2     2     2     4     8    11     5     9     4     4     7     4     1     1     2     5     2     0    74
     23.0      4     4     4     3     7    10     6    10     4     5     4     3     1     3     1     1     2     3    75
     24.0      1     5     5     1     5    16     9    10    12     1     3     4     2     1     3     1     3     0    82
   TOTALS     78    85    79    77    99   210   267   208   180    92    87    95    62    58    44    59    66    50

        0 WD3  VALUES LESS THAN   0.000             3886 WD3  VALUES LARGER THAN  180.0
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                TOWER   SITE

             FREQUENCY DISTRIBUTION OF  WD3  VS HOUR          WD3  RANGE  180.001 TO  360.0

                                                              ROW * COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                       W  D  3

            190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS
      1.0       2     1     5     8     5    15    20    14    10     6    10     6    12     5     7     7     5     2   140
 H    2.0       4     3     3     5     8    17    10    10     4     6     9     5     9     9     5     4     7     4   122
      3.0       3     2     4    11     8    12    14    21     7     7     6     8     6     8     9     5     1     5   137
 O    4.0       2     4     5     4     9    14    14     9    13     9     6    10     9     8     7     2     3     0   128
      5.0       0     1     2     8     5    12    17    14     8     6    11     8    12     3     7     3     0     1   118
 U    6.0       0     2     3     4    14    11    20     7     9    10     9     6     9     5     5     3     2     1   120
      7.0       1     0     5     6    11    15    11    16    13     5     4     5     2     9     2     2     5     3   115
 R    8.0       1     4     2     4    13    15    17    20     4     5     8     4     3     3     3     3     4     2   115
      9.0       1     0     6     3    20    13    31    15    14     5     5     4     5     2     2     3     1     0   130
     10.0       1     2     3    11    11    19    27    27    12     8     6     5     3     1     2     2     1     3   144
     11.0       4     5     8    12    16    24    25    29    17     7    10     4     7     5     2     1     4     0   180
     12.0       2     7     7    12    24    25    25    22    15     9     8    13     4     4     6     4     2     1   191
     13.0       2     5     7    17    28    24    19    18    13     6    12    12     9     3     7     5     0     7   193
     14.0       1     4     7    10    22    24    22    17    15    14    15    13     5     8     7     4     2     6   196
     15.0       5     1     4     9    36    24    15    19    13     7    14     7     9     8    10     2     7     6   196
     16.0       2     3     6    10    32    30    16    12    17     9    10    12    10     4     7     8     6     1   195
     17.0       3     2     3    11    20    18    25    20    15     7    10    11     8    10     3    13     9     8   195
     18.0       5     4     8    15    22    13    21    22    11     8    11     9    12     9     9    10     9     4   202
     19.0       8     3    10    19    13    10    21    21     9     9     6    14    15     7     4    12    11    11   205
     20.0       2     8     6     8    12    19    23    19    11    14    13    12     8    10     8     5    10     9   196
     21.0       0     5     6    10    13    12    16    18    12    11    13    11    16     5    10     6     4     5   173
     22.0       1     7     3     7    20    15    12    11     9    18     9    13    12    12     4     9     4     3   176
     23.0       5     2     7     6    17    13    13     9    19    12    13    12     7    11     7     7     4     3   167
     24.0       3     5     3     6    15    11    23    11    13     9     5    12    10     6     5    10     4     1   152
   TOTALS      58    80   123   216   394   406   457   400   283   207   223   216   208   155   138   130   106    86

       1895 WD3  VALUES LESS THAN 180.001              0 WD3  VALUES LARGER THAN  360.0
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                 MUNSEY  SITE

             FREQUENCY DISTRIBUTION OF  WD1  VS HOUR           WD1  RANGE    0.000 TO  180.0

                                                                ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                                  W  D  1

                10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 TOTALS
          1.0      1     2     3     4     2     1     2     2     5     4    17    43    78    47    43    25    14    10   303
  H       2.0      4     1     4     2     0     0     1     3     5     6    18    49    69    50    32    26    16     9   295
          3.0      5     2     2     0     4     1     4     2     1    10    10    38    47    60    39    23    22    15   285
  O       4.0      8     4     1     2     3     2     1     3     2     8    12    28    54    44    41    27    22    14   276
          5.0      6     3     2     1     0     2     2     3     3     5    12    27    50    40    34    21    24    12   247
  U       6.0      7     3     0     2     1     5     5     1     4     6    20    19    41    42    41    25    24    13   259
          7.0      9     8     3     8     2     1     4     4     7     9     5    24    29    34    20    24    13    10   214
  R       8.0     18    15    12    11     8     2     3     2     5     3     6    17    19     8    11    10     9     4   163
          9.0     26    16     9    12     5     5     1     0     4     3     3     5     3     7     9     5     3     1   117
         10.0     42    13    13    20     3     4     2     0     2     4     1     0     1     0     1     1     2     1   110
         11.0     29    19    15    10     8     4     2     1     3     1     0     0     1     2     2     2     1     0   100
         12.0     24    18    15     6     6     3     2     0     1     0     1     2     0     0     1     1     0     0    80
         13.0     25    16    11     5     3     4     2     2     1     0     0     2     0     2     2     1     0     0    76
         14.0     21    13     6     3     4     3     1     1     0     1     2     2     1     2     3     4     1     0    68
         15.0     15    10     8     5     3     2     1     2     3     4     4     1     1     3     3     2     4     3    74
         16.0     20    13     2     4     2     1     1     4     2     0     1     2     3     5     7     5     3     3    78
         17.0     20     9     8     4     0     2     1     0     2     1     2     2     1     7     8     5     5     4    81
         18.0     18     7     9     6     2     1     2     1     2     4     3     6     9    11    11    18    20    13   143
         19.0     12     5     7     3     2     2     0     6     3     5     8    10    30    30    26    31    26    17   223
         20.0     14     7     3     2     2     4     2     4     3     3    10    27    76    29    31    41    32    16   306
         21.0      7     5     1     1     4     2     4     3     2     5    14    45    86    49    34    24    33    19   337
         22.0      4     0     3     3     4     1     2     4     8     8    12    49   101    49    26    31    22    12   339
         23.0      5     7     2     3     2     1     2     2     6     7    17    64    84    47    24    21    21    17   332
         24.0      3     5     2     2     2     2     3     3     3     7    11    48    79    69    33    22    18     9   321
       TOTALS    343   201   141   119    72    55    50    51    77   104   189   510   863   636   482   395   335   202

            0 WD1  VALUES LESS THAN   0.000          5126 WD1  VALUES LARGER THAN  180.0
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              MUNSEY  SITE

           FREQUENCY DISTRIBUTION OF  WD1  VS HOUR          WD1  RANGE  180.001 TO  360.0

                                                            ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                    W  D  1

           190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

      1.0     8     6     3     5     5     8     6     7     6     4     5     7    13     4     5     6    10     7   115
 H    2.0     5     5     7     8     7     6    13     4     5     2     1     9    10     9     4     8     5     4   112
      3.0     9     6     2     4     2     9     6     4     9     8     4     8    11     4     3     6    11     7   113
 O    4.0    11     7     8     8     4     7     6     5     7     2     4    10    10     8     8     5    12     7   129
      5.0    10    10     7     8     7    12     7     8     8     4     8     6    13     9     6     4     5     6   138
 U    6.0    10     3    12     7     7    11    14     7     4     4     1     8     7     6     5     6     7    10   129
      7.0     7    13     7     5    10    10     7    10     6    11    13     6    14    10    14     7    11    12   173
 R    8.0     4     4     2    12     8    13     8     9     8     6     9    17    22    13    18    19    23    27   222
      9.0     3     2     4    10    17     8     8     4    10     7    15    29    16    20    21    34    34    40   282
     10.0     4     2     3     8     7     8     7    13    14    11    21    35    23    30    23    22    26    36   293
     11.0     5     2     4     6     8    13    13     8    22    18    19    45    40    30    30    12    17    18   310
     12.0     2     2     5     7    14    13    19    26    18    30    30    38    40    32    17    18    17    15   343
     13.0     2     0     3     9    14    20    14    18    25    30    33    54    34    19    27    15    16    15   348
     14.0     4     3     4     6    12    26    23    19    24    34    23    45    31    22    27    27    10    18   358
     15.0     2     3     4     7    19    17    18    18    27    27    31    30    36    20    20    31    19    23   352
     16.0     2     1     3    13    12    22    27    23    21    21    27    33    33    23    22    21    19    21   344
     17.0     7     9     4     9    11    27    18    19    22    13    13    35    30    22    25    20    25    24   333
     18.0     2     9     7    12    13    19    18    17     8    12     9    24    27    15    14    20    20    28   274
     19.0    10    12     7    12    11    12    10     4     7     5     7    11    21    15    14     6    16    33   213
     20.0    12     1     7     7    10    11     5     2     2     2     4     8    11     9     8     7    11    17   134
     21.0     3     2     5     8     6     6     7     3     3     1     1    11    10    10     8     7     4     8   103
     22.0     8     3     8     7     7     6     7     2     1     3     2     5    10     8     7     5     5     7   101
     23.0     8    11     1     5     6     6     5     2     6     4     8     5     7     9     6     2     5     6   102
     24.0    11     9     5     3     3     6     7     7    11     2     1     5     5     8     4     5     6     7   105
   TOTALS   149   125   122   186   220   296   273   239   274   261   289   484   474   355   336   313   334   396

     4827 WD1  VALUES LESS THAN 180.001              0 WD1  VALUES LARGER THAN  360.0
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TABLE 511

FREQUENCY DISTRIBUTION OF WD1 VS HOUR   WD1 RANGE 0.000 TO 180.0

ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

W D 1

		10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	130.0	140.0	150.0	160.0	170.0	180.0	TOTALS
	1.0	[illegible]	1	1	1	1	1	2	2	3	3	3	4	1	3	0	1	2	5	37
H	2.0	[illegible]	2	2	1	0	1	4	4	7	1	3	6	3	5	1	3	2	4	50
	3.0	[illegible]	2	0	1	0	2	0	4	3	7	8	6	1	3	3	3	6	3	53
O	4.0	[illegible]	2	1	1	2	1	0	2	3	9	10	3	1	8	3	4	3	1	54
	5.0	[illegible]	1	3	2	3	1	2	3	6	5	8	7	6	8	2	4	3	3	68
U	6.0	[illegible]	2	0	3	4	0	2	7	5	7	6	10	8	3	8	3	5	5	78
	7.0	[illegible]	2	5	1	3	2	7	4	5	3	7	8	4	12	3	5	5	4	82
R	8.0	[illegible]	3	4	2	3	1	6	2	14	14	14	7	5	4	4	5	10	3	103
	9.0	[illegible]	2	3	4	2	2	3	7	13	27	30	16	17	4	11	4	5	4	155
	10.0	[illegible]	[illegible]	1	2	2	4	4	9	8	20	27	24	16	16	5	6	3	2	153
	11.0	[illegible]	3	1	0	2	5	1	8	10	19	24	21	11	10	5	2	3	3	130
	12.0	[illegible]	1	1	3	0	4	4	4	9	10	21	11	9	10	6	5	3	3	107
	13.0	[illegible]	3	2	3	3	3	1	9	2	15	7	9	10	11	4	3	3	1	93
	14.0	[illegible]	0	4	2	2	2	3	8	6	11	4	4	7	3	4	3	4	5	74
	15.0	[illegible]	3	1	5	1	4	4	6	5	4	6	5	4	6	3	5	6	1	72
	16.0	[illegible]	3	1	4	5	3	4	5	6	6	4	2	4	6	3	0	2	5	64
	17.0	[illegible]	2	1	2	3	3	2	3	4	4	4	3	2	4	0	3	3	2	50
	18.0	[illegible]	[illegible]	3	0	2	5	4	2	8	3	3	1	8	2	2	0	4	6	57
	19.0	[illegible]	3	3	2	5	3	3	2	6	2	4	2	3	3	2	4	0	2	50
	20.0	[illegible]	2	2	5	3	3	5	3	2	4	1	5	6	4	3	2	5	3	61
	21.0	[illegible]	1	4	2	0	3	4	3	2	5	2	1	6	3	3	3	6	1	49
	22.0	[illegible]	3	0	2	3	3	2	1	2	4	2	0	0	6	3	4	1	2	40
	23.0	[illegible]	3	0	4	0	0	2	1	3	1	0	4	4	4	5	5	2	3	43
	24.0	[illegible]	1	1	3	1	3	0	1	6	2	3	7	4	4	3	5	5	1	53
	TOTALS	[illegible]	47	44	56	52	59	69	130	138	186	201	166	140	142	86	82	91	72	

0 WD1 VALUES LESS THAN 0.000   1806 WD1 VALUES LARGER THAN 180.0

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              CASTLE  SITE

          FREQUENCY DISTRIBUTION OF  WD1  VS HOUR            WD1  RANGE  180.001 TO  360.0

                                                             ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                         W  D  1

          190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS
     1.0      1     4     4     8     6     4     8    10     7    13    16    18    25    14    10     6     3     1   158
 H   2.0      6     5     3     5     8     9     9     4     8     7    16    21    11    15    12     3     0     3   145
     3.0      1     6     6     5     6     1     8     7    11    13     6    17    19    15     9     7     1     1   139
 O   4.0      3     2     7     5     7     6     7    10    10    12    12    18    16    12    13     3     1     1   145
     5.0      6     8     1     9     6     4     7     3    17    13    11    17    15    12    13     6     1     2   151
 U   6.0      5     8     2     6     6    11     5    10     8    10    16    12    18     7     3     4     1     2   134
     7.0      3     4     5     4     8     6     4     6     4    14    17    13    13    10    14     4     4     1   134
 R   8.0      3     1     0     7     6     9     3     7     7    10    13     5    15     7    11     8     5     1   118
     9.0      1     1     1     3     5     5     2     6     3     4     6    11    10    10     6    10     6     3    93
    10.0      1     4     1     2     3     3     1     5     7     6    12     9    11    12     6     5     3     4    95
    11.0      1     3     1     6     3     8     7     6     9    14    10    13     5    11     9    10     1     3   120
    12.0      3     2     1     2     4     8    16     9    17    14    22    13    13    11     7     5     8     3   157
    13.0      2     2     2     6    11    15    11    20    14    12    18     9    14    16    11     4     6     2   175
    14.0      1     0     2     6     4    11    20    21    19    13    13    22    12    15    15     6     7     5   192
    15.0      1     2     1     2     6    20    23    17    17    14    18    19    17     6     9    12     5     2   191
    16.0      3     3     6     6     6    18    19    15    12    16    15    21    18    12    16     9     2     7   204
    17.0      4     5     6     8     9    10    17    11    12    16    18    16    17    24    14    13     8     2   210
    18.0      3     3     4     7     3     8     8    16    19    20    13    15    18    20    13     9     5     6   190
    19.0      3     4     1     2     5    10    10     9    23    20    31    20    24    15    15     5     6     2   205
    20.0      5     2     2     4     5     6    10     9    18    20    19    26    26    15     5     2     4     2   180
    21.0      4     3     2     3     5     5     9    10    13    11    29    31    26    19     4     3     2     0   179
    22.0      2     3     3     3    11     5    10     5    16    16    28    26    13    21     7     2     3     0   174
    23.0      0     3     1     7     6     6     7    11    13    19    22    31    16    15     7     4     3     2   173
    24.0      1     3     0     3     6     4     8     7     8    12    20    25    22    12     6     2     4     1   144
  TOTALS     63    81    62   119   145   192   229   231   292   319   401   428   394   326   235   142    89    56

   1776 WD1  VALUES LESS THAN 180.001            0 WD1  VALUES LARGER THAN  360.0
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                          NASHS   SITE

                    FREQUENCY DISTRIBUTION OF  WD1  VS HOUR              WD1  RANGE    0.000 TO  180.0

                                                                          ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                                W  D  1

                10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 TOTALS
          1.0    14    27    24    18    35    21    17    17     4     0     4     1     2     1     0     0     0     2    187
 H        2.0    18    23    27    25    29    29    23     9     3     1     3     2     0     2     5     1     7     3    210
          3.0    10    17    22    24    34    24    23     9     5     5     2     1     4     2     0     2     5     6    195
 O        4.0    25    20    37    35    30    17    18     8     2     3     0     4     1     1     3     5     6     2    217
          5.0    17    26    34    25    20    22    22     9     8     4     2     0     2     2     2     2     4     3    204
 U        6.0    28    23    21    36    29    29    16     7     4     5     3     3     0     1     1     4     3     0    213
          7.0    16    17    29    34    28    26    17     5     4     5     5     3     2     1     3     3     3     2    203
 R        8.0    19    26    22    28    28    11     5     7    10     3     2     3     1     4     6     1     9     6    191
          9.0    19    15    13    19    14    15    12     2    12     4     4     4     7     3     5     4     7     9    168
         10.0    10     9    15    12    15    11    10    10     9     4     5     5     4     3     3     7     8     9    149
         11.0     9     8     6     3    17    10     6     7     2     4     3     7     6     2     7     4     4     5    110
         12.0     7     9     1     5    13     7    10     2     4     5     4     3     1     2     3     3     6     7     92
         13.0    13     4     7    10     4     8    10     6     6     4     2     2     1     1     3     4     4     4     93
         14.0    11     5     4    10     5     5     6     3     1     2     2     2     3     1     5     3     4     6     78
         15.0    11    11     3     4    10     3     7     3     3     3     2     2     2     1     1     3     3    10     82
         16.0    14     7     3     7     7     7     8     4     0     3     3     3     1     2     2     2     2     4     79
         17.0    13     9     4     3     8     8     3     2     3     4     1     0     1     2     2     1     3    10     77
         18.0    17     8     6     7     6    10     4     5     4     3     1     0     0     0     1     0     4     1     77
         19.0    23    15    12    10    13     6     6     7     1     1     1     1     0     1     0     2     2     2    103
         20.0    25    22    21    17    23    13    11     4     4     3     3     3     1     0     1     4     4     5    164
         21.0    19    24    24    46    26    27    14     6     4     3     3     5     4     1     2     0     2     5    215
         22.0     9    21    30    35    38    31    17     8    10     3     2     1     2     5     1     2     1     3    219
         23.0    14    20    23    45    35    32    13     7     6     2     4     1     2     1     2     3     3     7    220
         24.0     7    23    36    33    47    27    16     9     5     4     3     2     1     2     4     2     1     2    224
 TOTALS         368   389   424   491   514   399   294   156   114    78    64    58    48    41    62    62    95   113

          0 WD1  VALUES LESS THAN   0.000            5469 WD1  VALUES LARGER THAN  180.0
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NASHS SITE

FREQUENCY DISTRIBUTION OF WD1 VS HOUR   WD1 RANGE 180.001 TO 360.0

ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

W D 1

		190.0	200.0	210.0	220.0	230.0	240.0	250.0	260.0	270.0	280.0	290.0	300.0	310.0	320.0	330.0	340.0	350.0	360.0	TOTALS
	1.0	2	5	6	14	10	13	15	11	9	4	5	5	9	6	5	10	6	15	150
H	2.0	5	3	2	11	16	6	15	6	12	4	4	7	9	7	7	7	10	13	144
	3.0	4	5	10	5	16	13	6	9	9	2	1	4	6	8	13	7	16	18	152
O	4.0	4	6	8	9	8	13	12	8	9	4	6	3	4	8	10	7	10	19	148
	5.0	5	6	6	12	11	9	16	6	9	4	5	6	6	8	9	13	14	18	163
U	6.0	8	5	8	10	11	12	14	4	6	4	5	9	3	11	8	6	15	17	156
	7.0	3	3	9	14	16	12	6	11	9	3	5	2	6	5	13	5	19	19	160
R	8.0	3	3	6	13	16	20	18	15	8	6	8	6	5	4	10	9	20	10	180
	9.0	13	7	9	10	23	28	22	13	9	6	2	5	2	7	13	16	16	10	211
	10.0	11	15	10	22	21	49	24	18	6	8	3	4	7	8	7	6	13	8	240
	11.0	5	15	21	28	42	51	30	18	13	9	4	7	6	5	10	8	8	5	285
	12.0	9	13	20	31	44	46	37	26	18	8	12	6	9	5	8	11	8	10	321
	13.0	7	15	17	28	47	55	44	20	5	12	11	4	10	8	14	11	14	6	328
	14.0	9	15	19	22	57	45	35	17	11	12	12	8	9	11	15	22	16	10	345
	15.0	7	16	12	34	41	41	35	18	18	7	11	6	9	12	16	15	27	12	337
	16.0	11	11	13	22	43	54	28	18	13	6	9	8	17	6	16	16	29	20	340
	17.0	5	9	20	26	25	50	31	14	14	12	8	13	14	11	20	26	22	22	342
	18.0	7	14	15	21	34	41	30	13	5	10	13	11	11	12	21	22	29	21	330
	19.0	11	9	14	21	21	22	29	20	13	7	8	9	14	18	16	20	26	32	310
	20.0	4	10	9	20	25	18	16	9	12	6	9	6	12	10	12	13	15	20	226
	21.0	7	7	4	9	16	14	16	7	11	11	10	5	2	9	9	7	14	10	168
	22.0	3	10	11	15	7	10	9	9	6	7	4	5	6	6	10	8	8	12	146
	23.0	5	5	10	12	8	6	18	8	9	4	6	4	10	5	13	10	7	13	153
	24.0	5	8	7	15	17	10	10	7	6	3	5	4	5	3	4	7	12	6	134
	TOTALS	153	215	266	424	575	638	516	305	240	159	166	147	191	193	279	282	374	346	

1770 WD1 VALUES LESS THAN 180.001   0 WD1 VALUES LARGER THAN 360.0

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                  JOHNSN  SITE

               FREQUENCY DISTRIBUTION OF  WD1  VS HOUR          WD1  RANGE    0.000 TO  180.0

                                                                ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                               W  D  1

                 10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 TOTALS
         1.0       1     0     2     2     1     2     1     5     1     6     4     2     6    21    20    19    15    10   118
   H     2.0       0     2     1     2     1     2     3     4     0     4     5     5     5    21    16    18    21    14   124
         3.0       3     2     2     1     0     1     2     0     5     6     5     4    10    15    20    20    18    15   129
   O     4.0       2     1     1     1     1     1     1     2     1     2     3     5    10    10    21    17    23    15   117
         5.0       2     0     2     3     0     2     1     0     0     2     5     3     5    19    16    27    17    11   115
   U     6.0       3     2     1     0     0     1     0     2     3     2     2     3    11    10    22    23    16    10   111
         7.0       1     0     2     0     0     0     2     0     0     4     7     5     5    11    25    18    19    15   114
   R     8.0       1     3     1     0     1     1     0     1     5     4     7     2     5     2    10    11    22    23    99
         9.0       1     0     1     0     1     1     1     0     3    13    11     2     3     3     2     9    17    23    91
        10.0       1     1     1     2     0     2     0     1     6    14    11     4     1     4     2     6     9    23    88
        11.0       0     2     0     1     1     2     0     4     3    14     9     4     5     1     3     3     9    18    79
        12.0       1     1     1     2     1     2     2     2    13     9     8     3     0     2     1     4     7    17    76
        13.0       0     2     0     0     0     1     3     2    14    13     3     3     2     1     2     3    12    19    80
        14.0       1     0     0     0     0     0     1     3    12    18     3     2     0     2     1     3    12    16    74
        15.0       1     2     1     0     0     0     1     2    13    12     3     3     2     0     2     8     4    12    66
        16.0       1     1     0     2     1     1     1     4     9    16     1     4     1     1     3     3     5    13    67
        17.0       2     2     1     1     0     0     3     5     9    10     7     3     2     0     2     6    11    13    77
        18.0       4     2     2     0     1     3     1     5     8     9     9     4     1     1     1     9    11    14    85
        19.0       5     1     4     4     2     2     3     1     6     9     9     4     2     1    10    16    14    16   109
        20.0       2     0     4     4     2     2     2     3     1     7    14     5    14     8    12    24    18     7   129
        21.0       2     2     4     1     1     3     3     3     5     5     6     8     6     9    20    20    18     8   124
        22.0       2     1     3     0     2     2     5     2     3     7     5     7     6    14    26    27    18    11   141
        23.0       0     3     3     3     6     1     2     4     0     2     8     7     6    15    23    20    15     9   127
        24.0       1     5     1     0     4     1     2     4     2     4     5    12     9    22    17    23    19     7   138
      TOTALS      37    35    38    29    25    33    40    59   122   192   150   104   117   193   277   337   350   339

            0 WD1  VALUES LESS THAN   0.000           2922 WD1  VALUES LARGER THAN  180.0
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JOHNSN SITE

FREQUENCY DISTRIBUTION OF WD1 VS HOUR   WD1 RANGE 180.001 TO 360.0

ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

W D 1

		190.0	200.0	210.0	220.0	230.0	240.0	250.0	260.0	270.0	280.0	290.0	300.0	310.0	320.0	330.0	340.0	350.0	360.0	TOTALS
	1.0	1	0	2	2	4	3	4	7	5	9	12	6	3	14	16	7	4	0	99
H	2.0	5	2	1	0	4	1	0	4	7	2	19	8	5	9	15	8	3	4	97
	3.0	6	1	1	4	1	4	2	3	8	6	9	6	3	10	17	7	4	1	93
O	4.0	8	2	3	2	0	1	1	5	15	8	10	4	7	10	11	3	5	1	96
	5.0	6	2	1	4	1	3	3	5	9	9	10	7	10	13	11	4	3	1	102
U	6.0	5	3	2	1	4	1	3	5	6	10	9	9	8	13	11	7	3	2	102
	7.0	7	2	3	3	1	1	0	4	7	9	8	7	2	14	15	4	7	1	95
R	8.0	13	3	0	1	1	2	4	4	2	5	10	12	14	8	21	4	4	3	111
	9.0	11	5	9	2	5	2	3	3	2	2	3	9	17	19	19	10	4	2	130
	10.0	16	12	2	4	2	2	4	4	2	1	2	8	16	20	23	13	2	2	135
	11.0	20	9	3	6	2	4	6	0	2	2	2	6	13	34	22	8	4	2	151
	12.0	25	10	8	5	2	4	1	0	3	6	4	9	12	33	30	4	5	1	162
	13.0	16	17	10	3	3	2	6	3	3	4	3	5	15	32	21	5	5	6	159
	14.0	21	7	5	7	6	6	3	5	6	0	8	7	17	43	14	7	3	0	165
	15.0	16	17	7	9	4	4	4	2	4	6	6	14	15	30	21	8	3	2	172
	16.0	14	13	11	5	0	1	2	8	11	5	6	9	10	28	21	12	5	2	168
	17.0	17	9	2	4	6	2	3	8	4	1	8	10	17	28	11	16	3	4	153
	18.0	15	6	3	3	2	5	0	5	7	2	9	5	19	22	15	14	6	3	143
	19.0	13	3	1	0	5	1	2	4	3	4	10	8	14	17	13	16	5	3	123
	20.0	7	1	3	0	1	1	3	5	4	6	13	8	8	11	10	11	5	2	99
	21.0	8	2	2	2	1	3	1	3	9	12	8	4	6	11	9	5	3	6	95
	22.0	4	0	3	3	1	0	0	4	3	9	10	10	3	14	9	8	2	3	86
	23.0	5	1	3	0	4	6	4	2	3	7	10	10	5	12	11	6	9	0	98
	24.0	2	2	0	3	0	1	3	3	8	11	13	2	1	15	15	3	4	2	88
	TOTALS	270	130	92	73	60	60	62	96	133	136	202	183	240	460	381	190	101	53	

2478 WD1 VALUES LESS THAN 180.001   0 WD1 VALUES LARGER THAN 360.0

HOCKEY SITE

FREQUENCY DISTRIBUTION OF WSI VS HOUR WSI RANGE 0.001 TO 19.0

ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

		W S I																		
		1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	TOTAL
	1.0	71	101	77	58	19	20	9	6	1	3	2	0	1	0	0	0	0	0	0	368
H	2.0	81	97	80	51	23	21	8	4	3	2	1	0	0	1	0	0	0	0	0	372
	3.0	85	79	83	53	27	17	10	5	3	1	2	0	1	0	0	0	0	0	0	366
O	4.0	78	90	79	52	27	20	6	3	3	3	0	0	1	0	0	0	0	0	0	362
	5.0	73	98	79	46	28	14	8	3	5	2	0	0	0	0	0	0	0	0	0	356
U	6.0	86	95	74	46	25	10	10	4	7	2	1	0	0	0	0	0	0	0	0	360
	7.0	78	95	73	47	24	18	6	5	3	2	1	1	0	0	0	0	0	0	0	353
R	8.0	98	79	61	41	34	13	12	8	1	1	2	1	1	0	0	0	0	0	0	352
	9.0	101	84	57	41	28	19	8	10	6	3	1	2	0	0	0	0	0	0	0	360
	10.0	109	82	58	38	31	18	13	10	7	3	3	0	0	0	0	0	0	0	0	372
	11.0	99	85	46	55	26	15	17	11	13	3	0	0	1	0	0	0	0	0	0	371
	12.0	99	75	59	33	45	21	14	15	14	5	2	1	0	0	0	0	0	0	0	383
	13.0	75	93	51	46	31	32	20	13	10	4	4	1	0	0	1	0	0	0	0	381
	14.0	83	83	55	52	34	22	26	9	11	5	2	1	1	0	0	1	0	0	0	385
	15.0	72	90	52	41	50	22	19	15	8	3	4	0	1	0	0	1	0	0	0	378
	16.0	58	92	53	53	39	27	21	14	9	5	3	1	0	2	0	0	0	0	0	377
	17.0	71	90	62	52	29	29	24	8	3	7	5	0	1	0	0	0	0	0	0	381
	18.0	71	69	83	49	40	24	17	9	10	1	0	2	0	0	0	0	0	0	0	375
	19.0	54	92	90	51	35	30	9	3	11	2	1	0	1	0	0	0	0	0	0	379
	20.0	74	92	93	38	42	22	7	6	2	5	1	2	0	0	0	0	0	0	0	384
	21.0	71	106	78	45	37	20	5	6	6	2	1	0	0	0	0	0	0	0	0	377
	22.0	82	91	85	43	32	22	5	6	5	5	1	1	0	0	0	0	0	0	0	378
	23.0	89	81	83	49	27	23	11	5	3	5	1	1	0	0	0	0	0	0	0	378
	24.0	83	94	76	44	33	15	12	6	5	1	1	1	0	0	0	0	0	0	0	371
	TOTALS	1941	2133	1687	1124	766	494	297	184	149	75	39	15	9	3	1	2	0	0	0	

2 WSI VALUES LESS THAN 0.001 0 WSI VALUES LARGER THAN 19.0

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                      HOCKEY  SITE

                  FREQUENCY DISTRIBUTION OF  WS3  VS HOUR          WS3  RANGE    0.001 TO   19.0

                                                                   ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                            W  S  3

                  1.0   2.0   3.0   4.0   5.0   6.0   7.0   8.0   9.0  10.0  11.0  12.0  13.0  14.0  15.0  16.0  17.0  18.0  19.0 TOTAL
        1.0        13    29    70    80    71    37    21     9    10     5     2     1     2     0     0     0     1     0     0   351
  H     2.0         6    41    69    85    55    40    26    10    10     1     3     0     1     0     0     0     1     0     0   348
        3.0         9    41    70    82    56    39    21    11     7     6     1     1     1     0     1     0     0     0     0   346
  O     4.0        11    30    71    86    63    43    18    10     5     4     4     0     0     0     1     0     0     0     0   346
        5.0         5    49    62    90    57    42    12    10     6     5     1     1     0     0     0     0     0     0     0   340
  U     6.0        14    46    67    79    69    34     8     8    10     3     2     1     1     0     0     0     0     0     0   342
        7.0        15    49    82    71    55    36    21     6     6     4     1     1     0     1     0     0     0     0     0   348
  R     8.0        22    63    79    57    47    37    10    11     8     1     3     2     2     0     0     0     0     0     0   342
        9.0        29    71    78    55    42    31     8     9     8     3     3     4     1     0     0     0     0     0     0   342
       10.0        33    63    76    45    50    25    15     5     6     9     2     3     0     0     0     0     0     0     0   332
       11.0        19    75    71    50    29    29    23    13    11     9     2     0     2     0     0     0     0     0     0   333
       12.0        21    56    75    47    40    33    22    19    11     8     4     2     1     1     0     0     0     0     0   340
       13.0        20    61    49    54    39    39    31    17    18     3     2     5     0     0     0     0     0     0     0   338
       14.0        12    53    51    56    48    27    36    23    16     5     3     2     1     1     0     0     0     0     0   334
       15.0        10    40    65    55    49    37    22    31    11     4     4     2     2     1     0     0     1     0     0   334
       16.0        14    34    47    60    62    36    28    21    10    10     6     2     1     1     2     0     0     0     0   334
       17.0        12    31    64    59    59    36    28    21     5    11     4     6     1     0     0     0     0     0     0   337
       18.0        10    34    50    64    63    51    20    18    11     8     1     4     2     0     0     0     0     0     0   336
       19.0        13    23    54    76    65    51    30    14     6     7     2     4     0     1     0     0     0     0     0   346
       20.0         8    24    52    92    67    49    23    17     4     3     4     5     2     0     0     0     0     0     0   350
       21.0         6    24    70    84    70    38    28    13     7     7     4     2     0     1     0     0     0     0     0   354
       22.0        11    22    68    79    65    44    31    17     4     6     4     2     0     1     1     0     0     0     0   355
       23.0        10    28    56    88    69    33    32    15     9     4     5     3     0     1     0     0     0     0     0   353
       24.0         8    33    69    82    65    32    28    16     7     8     1     1     1     1     0     0     0     0     0   352
     TOTALS       331  1020  1565  1676  1355   899   542   344   206   134    68    54    21    10     5     0     3     0     0

           11 WS3  VALUES LESS THAN   0.001              0 WS3  VALUES LARGER THAN   19.0
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                    LAMBER  SITE
          FREQUENCY DISTRIBUTION OF  WS1  VS HOUR            WS1  RANGE    0.001 TO  .19.0
                                                             ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                            W  S  1
                1.0   2.0   3.0   4.0   5.0   6.0   7.0   8.0   9.0  10.0  11.0  12.0  13.0  14.0  15.0  16.0  17.0  18.0  19.0 TOTAL
        1.0     132    54    24    18     4     4     2     0     0     0     0     1     0     0     0     0     0     0     0   239
   H    2.0     142    42    33    12     6     1     1     0     0     0     0     0     1     0     0     0     0     0     0   238
        3.0     143    49    24    15     5     2     1     0     0     0     0     1     0     0     0     0     0     0     0   240
   O    4.0     141    51    27    13     6     1     0     1     0     0     0     0     1     0     0     0     0     0     0   241
        5.0     134    48    25    16     7     2     1     0     0     1     0     0     0     0     0     0     0     0     0   234
   U    6.0     133    56    20    17     4     3     2     0     0     0     0     0     0     0     0     0     0     0     0   235
        7.0     142    48    21    10     9     2     0     2     0     0     0     0     0     0     0     0     0     0     0   234
   R    8.0     131    49    30    16     6     1     0     1     1     0     0     0     0     0     0     0     0     0     0   235
        9.0     122    45    30    14    12     7     1     0     0     1     0     0     0     0     0     0     0     0     0   232
       10.0      87    68    40    17    12     4     1     2     0     1     0     0     0     0     0     0     0     0     0   232
       11.0      63    71    45    19    19     8     1     1     3     0     0     0     0     0     0     0     0     0     0   230
       12.0      51    84    37    26    17    11     2     2     3     1     0     0     0     0     0     0     0     0     0   234
       13.0      38    83    51    24    18    11     4     2     1     1     0     0     0     0     0     0     0     0     0   233
       14.0      31    89    44    30    16     9     6     5     1     0     2     0     0     0     0     0     0     0     0   233
       15.0      29    80    43    37    15    12     6     4     3     2     0     0     0     0     0     0     0     0     0   231
       16.0      20    89    56    24    20    11     8     5     1     2     0     0     0     0     0     0     0     0     0   236
       17.0      31    98    44    31    16     3     8     2     1     0     1     0     0     0     0     0     0     0     0   235
       18.0      33   101    50    21    12    12     1     2     1     0     0     0     0     0     0     0     0     0     0   233
       19.0      62    93    41    23     9     8     1     1     0     0     0     0     0     0     0     0     0     0     0   238
       20.0      97    69    34    21     8     5     2     0     0     0     1     0     0     0     0     0     0     0     0   237
       21.0     112    62    29    21     8     5     1     1     0     0     0     0     0     0     0     0     0     0     0   239
       22.0     114    67    27    17     7     4     2     1     0     0     0     0     0     0     0     0     0     0     0   239
       23.0     119    63    24    11    10     9     1     1     0     0     0     0     0     0     0     0     0     0     0   238
       24.0     131    53    22    21     5     6     1     1     0     0     0     0     0     0     0     0     0     0     0   240
     TOTALS    2239  1612   821   474   251   141    51    34    15     9     4     2     2     0     0     0     0     0     0

           3 WS1  VALUES LESS THAN   0.001                    0 WS1  VALUES LARGER THAN   19.0
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                  TOWER   SITE

              FREQUENCY DISTRIBUTION OF  WS1  VS HOUR          WS1  RANGE    0.001 TO   19.0

                                                               ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                        W  S  1

              1.0   2.0   3.0   4.0   5.0   6.0   7.0   8.0   9.0  10.0  11.0  12.0  13.0  14.0  15.0  16.0  17.0  18.0  19.0 TOTAL
      1.0     133    78    40    22     8     7     2     2     0     0     0     0     0     0     0     0     0     0     0   292
 H    2.0     109    72    30    14    11     3     1     1     1     0     0     0     0     0     0     0     0     0     0   242
      3.0     126    80    41    18    13     3     0     3     0     0     0     0     0     0     0     0     0     0     0   284
 O    4.0     125    76    31    19    13     9     1     2     0     0     0     0     0     0     0     0     0     0     0   276
      5.0     111    78    40    21     9     4     1     1     0     0     0     0     0     0     0     0     0     0     0   265
 U    6.0     114    90    34    20    13     2     1     2     0     0     0     0     0     0     0     0     0     0     0   276
      7.0     122    86    31    15    12     5     1     0     0     1     0     0     0     0     0     0     0     0     0   273
 R    8.0     132    81    24    27     7     7     2     3     0     0     0     0     0     0     0     0     0     0     0   283
      9.0     142    69    39    20    10     9     3     2     0     0     1     0     0     0     0     0     0     0     0   295
     10.0     109    81    49    28     9    11     2     2     1     0     0     1     0     0     0     0     0     0     0   293
     11.0      69    85    62    44    16    10     4     4     0     0     0     1     0     1     0     0     0     0     0   296
     12.0      53    74    69    49    25    15     8     5     2     1     2     1     0     0     0     0     0     0     0   304
     13.0      46    69    77    41    34    21     8     5     3     2     1     0     1     1     0     0     0     0     0   309
     14.0      39    66    63    61    26    16    14     7     5     2     2     0     1     0     0     0     0     0     0   302
     15.0      29    62    77    56    35    20    10     6     7     1     2     0     1     0     0     0     0     0     0   306
     16.0      37    53    84    53    38    20    13     7     4     1     1     3     0     0     0     0     0     0     0   314
     17.0      31    77    64    71    27    23    11     3     2     2     2     1     0     0     0     0     0     0     0   314
     18.0      33    74   102    49    25    14     8     6     2     1     0     1     0     0     0     0     0     0     0   315
     19.0      54   112    79    38    22    12     7     0     3     0     0     0     0     0     0     0     0     0     0   327
     20.0      83   119    60    32    20     7     6     3     0     0     0     0     0     0     0     0     0     0     0   330
     21.0     113   102    48    26    10    10     3     2     1     0     0     0     0     0     0     0     0     0     0   315
     22.0     114   101    51    29     8     9     2     1     0     0     0     0     0     0     0     0     0     0     0   315
     23.0     124    94    49    22    11     8     1     0     0     0     0     0     0     0     0     0     0     0     0   309
     24.0     120    94    29    22    11     8     2     2     0     0     0     0     0     0     0     0     0     0     0   288
   TOTALS    2168  1973  1273   797   413   253   111    69    31    11    11     8     3     2     0     0     0     0     0

        1 WS1  VALUES LESS THAN   0.001              0 WS1  VALUES LARGER THAN   19.0
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TOWER SITE

FREQUENCY DISTRIBUTION OF WS3 VS HOUR   WS3 RANGE 0.001 TO 19.0

ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

		W	S	3																	
		1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	TOTAL
	1.0	61	72	34	18	22	11	4	0	2	0	0	0	0	0	0	0	0	0	0	224
H	2.0	67	54	36	20	12	6	0	1	2	1	0	0	0	0	0	0	0	0	0	199
	3.0	70	65	38	25	9	9	3	3	0	0	0	0	0	0	0	0	0	0	0	222
O	4.0	70	54	43	23	12	9	6	1	1	0	0	0	0	0	0	0	0	0	0	219
	5.0	54	66	41	19	16	9	0	1	0	0	0	1	0	0	0	0	0	0	0	207
U	6.0	55	68	42	24	12	8	2	1	1	1	0	0	0	0	0	0	0	0	0	214
	7.0	62	75	31	19	14	6	4	1	1	1	0	0	0	0	0	0	0	0	0	214
R	8.0	83	61	33	13	17	5	7	1	2	1	0	0	0	0	0	0	0	0	0	223
	9.0	78	58	32	25	14	10	4	2	1	1	0	1	0	0	0	0	0	0	0	226
	10.0	74	61	39	31	13	6	8	3	1	1	0	0	0	1	0	0	0	0	0	238
	11.0	41	57	53	40	26	9	8	9	1	0	0	0	1	1	0	0	0	0	0	246
	12.0	34	47	50	47	32	12	13	5	3	4	2	0	1	1	0	0	0	0	0	251
	13.0	34	30	66	41	24	24	14	7	6	1	1	3	0	0	0	0	0	0	0	251
	14.0	21	33	46	47	41	27	8	13	4	5	4	0	0	0	0	0	0	0	0	249
	15.0	20	37	42	54	34	24	22	8	7	3	1	1	1	1	0	0	0	0	0	255
	16.0	20	30	45	59	35	29	15	11	4	4	2	1	1	1	0	0	0	0	0	257
	17.0	7	45	52	51	40	23	17	8	3	5	2	2	0	0	0	0	0	0	0	255
	18.0	15	40	72	56	34	20	11	4	3	4	1	0	1	0	0	0	0	0	0	261
	19.0	12	67	69	49	26	20	7	6	1	4	1	0	0	0	0	0	0	0	0	262
	20.0	32	71	65	48	23	12	6	6	4	0	0	0	0	0	0	0	0	0	0	267
	21.0	46	82	53	37	16	7	4	3	2	1	1	0	0	0	0	0	0	0	0	252
	22.0	58	77	47	38	14	8	6	2	1	0	0	0	0	0	0	0	0	0	0	251
	23.0	59	68	49	33	19	6	5	1	0	0	0	0	0	0	0	0	0	0	0	240
	24.0	69	68	37	28	16	10	4	1	1	1	0	0	0	0	0	0	0	0	0	235
TOTALS		1142	1386	1115	845	571	310	178	98	51	38	15	9	5	5	0	0	0	0	0	

25 WS3 VALUES LESS THAN 0.001   0 WS3 VALUES LARGER THAN 19.0

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                                    MUNSEY  SITE

                               FREQUENCY DISTRIBUTION OF  WS1  VS HOUR            WS1  RANGE    0.001 TO   19.0

                                                                                  ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                                           W  S  1

                       1.0   2.0   3.0   4.0   5.0   6.0   7.0   8.0   9.0  10.0  11.0  12.0  13.0  14.0  15.0  16.0  17.0  18.0  19.0 TOTAL
            1.0        365    47    18     3     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0   434
      H     2.0        352    52    17     3     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   424
            3.0        362    45    12     4     2     0     0     0     0     0     0     0     0     0     0     0     0     0     0   425
      O     4.0        364    42    16     6     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   428
            5.0        369    42    13     3     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   427
      U     6.0        371    38    15     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   425
            7.0        371    41    11     2     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   426
      R     8.0        350    54    16     3     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   423
            9.0        316    83    17     4     1     1     0     0     0     0     0     0     0     0     0     0     0     0     0   422
           10.0        256   126    25     9     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0   417
           11.0        200   155    47    10     2     1     0     0     0     0     0     0     0     0     0     0     0     0     0   415
           12.0        182   162    67    14     3     1     0     0     0     0     0     0     0     0     0     0     0     0     0   429
           13.0        160   174    71    16     5     1     0     0     0     0     0     0     0     0     0     0     0     0     0   427
           14.0        147   175    80    21     6     1     0     0     0     0     0     0     0     0     0     0     0     0     0   430
           15.0        153   170    78    21     5     3     0     0     0     0     0     0     0     1     0     0     0     0     0   431
           16.0        132   186    77    23     6     2     1     1     0     0     0     0     0     0     0     0     0     0     0   428
           17.0        157   161    77    15     5     1     2     0     0     0     0     0     0     0     0     0     0     0     0   418
           18.0        196   142    71    10     2     1     0     0     0     0     0     0     0     0     0     0     0     0     0   422
           19.0        223   166    41     9     2     0     0     0     0     0     0     0     0     0     0     0     0     0     0   441
           20.0        204   190    44     5     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   444
           21.0        237   177    25     6     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   446
           22.0        290   134    15     6     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0   446
           23.0        338    84    14     8     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   445
           24.0        341    72    17     6     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0   437
         TOTALS       6436  2718   884   208    43    16     3     1     0     0     0     0     0     1     0     0     0     0     0

                 7 WS1  VALUES LESS THAN   0.001                  0 WS1  VALUES LARGER THAN   19.0
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                    CASTLE  SITE

                 FREQUENCY DISTRIBUTION OF  WS1  VS HOUR          WS1  RANGE    0.001 TO   19.0

                                                                  ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                              W  S  1

                1.0   2.0   3.0   4.0   5.0   6.0   7.0   8.0   9.0  10.0  11.0  12.0  13.0  14.0  15.0  16.0  17.0  18.0  19.0 TOTAL
         1.0    236    19     9     1     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   266
  H      2.0    230    21     7     2     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   260
         3.0    231    18     6     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   256
  O      4.0    231    22     7     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   260
         5.0    240    18     3     2     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   263
  U      6.0    234    19     7     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   260
         7.0    235    17     5     3     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   261
  R      8.0    226    22     7     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   256
         9.0    227    24     9     2     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   263
        10.0    205    36    16     2     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   260
        11.0    175    51    30     2     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   259
        12.0    148    81    31     7     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   268
        13.0    136    88    39     9     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   273
        14.0    115    98    46     8     2     0     1     0     0     0     0     0     0     0     0     0     0     0     0   270
        15.0    115    97    43    10     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   266
        16.0    113   111    36    11     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0   272
        17.0    136    98    26     7     1     1     0     0     0     0     0     0     0     0     0     0     0     0     0   269
        18.0    169    70    18     6     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   263
        19.0    202    51    12     5     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   270
        20.0    227    33    12     2     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   274
        21.0    228    25    12     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   266
        22.0    234    26     6     2     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0   268
        23.0    230    17    11     1     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   260
        24.0    231    16    10     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0   258
      TOTALS   4751  1078   408    84    14     2     1     0     0     0     0     0     0     0     0     0     0     0     0

             7 WS1  VALUES LESS THAN   0.001            0 WS1  VALUES LARGER THAN   19.0
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NASHS SITE

FREQUENCY DISTRIBUTION OF WSI VS HOUR WSI RANGE 0.001 TO 19.0

ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

		W S I																		
		1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	TOTAL
	1.0	326	38	16	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	386
H	2.0	326	39	15	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	387
	3.0	325	40	14	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	382
O	4.0	331	44	10	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	391
	5.0	341	33	14	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	393
U	6.0	327	44	11	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	386
	7.0	325	48	9	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	385
R	8.0	316	52	16	5	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	392
	9.0	285	61	31	9	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	389
	10.0	223	96	42	18	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	384
	11.0	172	109	54	41	8	2	3	0	0	0	0	0	0	0	0	0	0	0	0	389
	12.0	138	106	82	46	20	4	2	3	0	0	0	0	0	0	0	0	0	0	0	401
	13.0	123	110	93	46	28	6	2	0	1	0	0	0	0	0	0	0	0	0	0	409
	14.0	100	140	85	52	24	8	1	2	0	0	0	0	0	0	0	0	0	0	0	412
	15.0	106	119	91	53	25	6	5	0	0	0	0	0	0	0	0	0	0	0	0	405
	16.0	107	126	94	59	14	7	1	0	0	0	0	0	0	0	0	0	0	0	0	408
	17.0	104	153	89	39	20	3	0	0	0	0	0	0	0	0	0	0	0	0	0	408
	18.0	140	166	60	21	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	396
	19.0	230	112	55	10	3	1	0	0	0	0	0	0	1	0	0	0	0	0	0	412
	20.0	283	82	26	4	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	399
	21.0	318	56	21	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	399
	22.0	333	44	15	8	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	402
	23.0	332	46	18	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	404
	24.0	329	38	21	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	392
	TOTALS	5940	1912	982	444	175	45	15	6	1	0	0	0	1	0	0	0	0	0	0	

39 WSI VALUES LESS THAN 0.001 0 WSI VALUES LARGER THAN 19.0

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                    JOHNSN  SITE
              FREQUENCY DISTRIBUTION OF  WS1  VS HOUR          WS1  RANGE    0.001 TO   19.0
                                                               ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                            W  S  1
               1.0   2.0   3.0   4.0   5.0   6.0   7.0   8.0   9.0  10.0  11.0  12.0  13.0  14.0  15.0  16.0  17.0  18.0  19.0 TOTAL
       1.0     117    56    31    15     7     3     0     1     0     0     0     0     0     0     0     0     0     0     0   230
  H    2.0     117    66    26    12     7     3     1     0     0     0     0     0     0     0     0     0     0     0     0   232
       3.0     128    61    27    14     5     2     1     0     0     0     0     0     0     0     0     0     0     0     0   238
  O    4.0     118    64    21    16     5     2     1     0     0     0     0     0     0     0     0     0     0     0     0   227
       5.0     137    51    27    11     4     1     0     0     0     0     0     0     0     0     0     0     0     0     0   231
  U    6.0     131    59    25     8     1     2     2     0     0     0     0     0     0     0     0     0     0     0     0   228
       7.0     110    78    22     8     3     1     1     1     0     0     0     0     0     0     0     0     0     0     0   224
  R    8.0      99    87    24     9     2     0     0     2     0     0     0     0     0     0     0     0     0     0     0   223
       9.0      83    98    35    11     3     2     0     0     1     0     0     0     0     0     0     0     0     0     0   233
      10.0      57   100    44    18     7     2     3     0     0     0     0     0     0     0     0     0     0     0     0   231
      11.0      48   100    58    22     4     3     1     1     0     0     0     0     0     0     0     0     0     0     0   237
      12.0      40    98    63    32     6     4     1     1     0     0     0     0     0     0     0     0     0     0     0   245
      13.0      46    95    60    25    10     5     2     0     1     0     0     0     0     0     0     0     0     0     0   244
      14.0      42    93    62    25    13     2     2     2     2     0     0     0     0     0     0     0     0     0     0   243
      15.0      31   107    60    22    10     5     3     3     0     1     0     0     0     0     0     0     0     0     0   242
      16.0      46    90    58    24    12     5     2     2     1     1     0     0     0     0     0     0     0     0     0   242
      17.0      55    92    47    26     9     4     3     1     0     0     2     0     0     0     0     0     0     0     0   239
      18.0      66    81    55    16    13     2     2     2     0     0     0     0     0     0     0     0     0     0     0   237
      19.0      94    78    37    18     6     2     4     0     0     0     0     0     0     0     0     0     0     0     0   239
      20.0     116    71    23    17     4     6     2     0     0     0     0     0     0     0     0     0     0     0     0   239
      21.0     108    67    33    13     4     1     2     0     0     0     0     0     0     0     0     0     0     0     0   228
      22.0     123    56    37     9    10     1     3     0     0     0     0     0     0     0     0     0     0     0     0   239
      23.0     133    46    34    16     3     4     1     1     0     0     0     0     0     0     0     0     0     0     0   238
      24.0     125    56    29    17     9     3     1     0     0     0     0     0     0     0     0     0     0     0     0   240
    TOTALS    2170  1850   938   404   157    65    38    17     5     2     2     0     0     0     0     0     0     0     0
          0 WS1  VALUES LESS THAN   0.001              0 WS1  VALUES LARGER THAN   19.0
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                           HOCKEY  SITE

                      FREQUENCY DISTRIBUTION OF  SG1  VS HOUR          SG1  RANGE    0.001 TO  120.0

                                                                       ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                                 S  G  1

                  10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 TOTALS

          1.0      97   193    68    30    20    13    10     3     5     0     0     0   439

  H       2.0      77   208    74    41    14    12     9     2     3     0     0     0   440

          3.0      85   204    76    29    12    13     8     4     0     0     1     0   433

  O       4.0      78   206    75    28    20    12     3     4     4     0     1     0   431

          5.0      86   181    80    35    20     9    14     2     2     2     0     0   431

  U       6.0      87   175    73    29    20    14    13     5     9     4     0     0   429

          7.0      78   182    79    37    21    12     9     4     4     2     1     1   430

  R       8.0      57   190    79    30    25    16    10    10     6     5     0     0   428

          9.0      43   164    81    49    45    24    11     9     3     1     0     0   430

         10.0      28   159    95    45    43    28    24    11     5     3     0     0   438

         11.0      21   117    85    68    58    45    21    10     4     2     2     0   433

         12.0      15   120    95    45    54    41    30    16    16     4     0     0   436

         13.0      12   129    95    51    42    46    30    17    12     3     3     0   440

         14.0      16   119    96    50    48    37    39    18    11     5     0     0   439

         15.0      14   131    89    62    57    33    30    12    10     3     2     0   443

         16.0      17   137   102    50    39    43    23    17    10     2     0     0   440

         17.0      19   158   110    41    42    30    22    15     5     1     0     0   443

         18.0      49   170   109    27    21    24    18    12    10     4     0     0   444

         19.0      59   212    77    23    22    19    15     4    10     3     0     0   444

         20.0      80   195    78    30    18    13    12    10     6     1     3     0   446

         21.0      81   194    81    35    19    12    12     8     3     1     1     0   447

         22.0      76   212    73    31    19    15    10     6     2     0     0     0   444

         23.0      90   197    72    32    23     9     8     4     7     2     0     1   444

         24.0      89   188    76    46    14    10     7     3     6     3     0     0   442

       TOTALS    1355  4137  2018   944   716   523   388   206   154    51    14     2

            9 SG1  VALUES LESS THAN   0.001               0 SG1  VALUES LARGER THAN  120.0
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                    HOCKEY  SITE

                FREQUENCY DISTRIBUTION OF  SG3  VS HOUR          SG3  RANGE    0.001 TO  120.0

                                                                 ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                              S  G  3

               10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 TOTALS

        1.0     178   122    30    16     8     8     4     0     2     0     0     0   368
  H     2.0     151   154    37    11     4     1     2     3     2     1     0     0   366
        3.0     158   152    25     5     8     3     6     4     0     0     0     0   361
  O     4.0     157   151    25    10     4     8     3     1     1     0     0     0   360
        5.0     155   144    28    21     5     3     3     0     1     0     0     0   360
  U     6.0     140   140    33    15    13     8     5     4     2     0     0     0   360
        7.0     142   146    36    12     9     6     5     1     3     0     0     0   360
  R     8.0     117   132    55    22    16     3     5     6     4     0     0     0   360
        9.0      99   131    53    36    21     8     5     2     5     2     1     0   363
       10.0      64   149    59    41    10    13    12     7     3     3     0     0   361
       11.0      47   115    82    48    32    16    11     2     1     2     1     0   357
       12.0      32   126    73    55    27    14    11     8     3     4     1     0   354
       13.0      32   141    71    50    23    16    10     6     3     9     0     0   361
       14.0      27   153    77    44    19    19     8     7     2     3     0     0   359
       15.0      35   151    79    45    21    16     7     6     3     2     0     0   365
       16.0      49   161    79    30    19     5     8     9     2     1     0     0   363
       17.0      69   163    71    29    14    10    10     0     0     0     0     0   366
       18.0     103   171    49    12     9     6     6     5     3     1     0     0   365
       19.0     135   169    25     7     6     9     8     4     1     0     0     0   364
       20.0     160   150    23     8     7     6     7     3     3     1     0     0   368
       21.0     163   144    27    17     8     3     3     3     1     1     0     0   370
       22.0     151   155    25    17     9     4     2     2     1     3     0     0   369
       23.0     175   122    28    15     9     6     3     7     2     1     0     0   368
       24.0     166   133    37     7    10     5     6     4     1     0     0     0   369
     TOTALS    2705  3475  1127   574   311   196   150    94    49    34     3     0

          14 SG3  VALUES LESS THAN   0.001            0 SG3  VALUES LARGER THAN  120.0
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LAMBER SITE

FREQUENCY DISTRIBUTION OF SG1 VS HOUR   SG1 RANGE 0.001 TO 120.0

ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

S G 1

		10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	TOTALS
	1.0	9	53	41	21	20	9	15	17	22	10	3	0	220
H	2.0	15	50	36	12	21	10	13	19	29	12	3	0	220
	3.0	13	58	34	15	12	15	18	26	18	17	0	0	220
O	4.0	13	45	34	23	19	18	21	20	15	10	1	0	219
	5.0	19	46	34	22	11	13	13	21	28	9	0	0	216
U	6.0	13	63	28	23	19	15	11	11	19	12	2	0	216
	7.0	15	50	31	28	19	16	19	13	17	6	1	0	216
R	8.0	10	48	43	26	13	16	16	16	19	8	0	0	215
	9.0	10	66	32	14	23	19	19	9	12	11	1	0	216
	10.0	14	61	37	26	16	17	15	14	11	4	0	0	215
	11.0	17	59	39	22	21	17	3	13	6	8	0	0	215
	12.0	10	73	48	19	21	16	8	6	8	7	1	0	217
	13.0	13	73	45	20	22	14	13	10	3	5	0	0	218
	14.0	19	68	47	21	19	14	13	4	5	4	0	0	214
	15.0	20	77	42	22	22	19	9	7	3	0	0	0	221
	16.0	14	91	40	36	11	9	11	4	3	0	1	0	220
	17.0	19	85	56	23	19	5	8	4	2	1	1	0	224
	18.0	18	101	52	18	14	5	4	3	6	2	0	0	223
	19.0	10	91	54	22	10	9	10	7	6	5	1	0	225
	20.0	13	81	46	23	16	5	9	14	5	10	0	0	222
	21.0	13	66	40	16	19	6	13	24	14	4	2	0	221
	22.0	9	68	38	18	12	15	19	14	14	10	3	0	219
	23.0	17	55	41	14	13	16	14	19	19	7	3	0	218
	24.0	14	56	36	26	13	15	13	23	15	6	1	0	219
	TOTALS	337	1594	974	510	405	314	306	313	299	172	21	0	

5 SG1 VALUES LESS THAN 0.001   0 SG1 VALUES LARGER THAN 120.0

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                 TOWER   SITE
              FREQUENCY DISTRIBUTION OF  SG1  VS HOUR          SG1  RANGE    0.001 TO  120.0
                                                               ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                              S  G  1

               10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 TOTALS
        1.0     16    91    82    44    37    24    17    11    16     5     2     0   345
  H     2.0     21   101    54    43    36    33    24    10    11     7     0     0   340
        3.0     19    93    63    47    32    26    25    15     7     7     3     0   337
  O     4.0     20    85    66    45    45    22    22    15    15     3     1     0   339
        5.0     28    98    64    42    31    16    25    10     8     7     0     0   329
  U     6.0     24   112    65    33    29    24    16    10     9     4     0     0   326
        7.0     23   107    74    36    31    13    16    14     9     6     1     0   330
  R     8.0     17    92    69    50    37    16    14    14    16     4     1     0   330
        9.0     14   102    64    43    29    14    18    18    16    11     2     0   331
       10.0     16    75    78    46    36    20    19    23    16     5     0     0   334
       11.0      7    74    92    51    37    20    21    16     8     8     3     0   337
       12.0      9    88    84    48    42    27    19    12    12     3     3     0   347
       13.0      4    78    85    48    45    32    17    22     9     4     2     0   346
       14.0      3    79    83    49    46    38    19     8    13     6     1     0   345
       15.0      4    94    90    43    45    29    19    18     8     2     1     0   353
       16.0      7    98    74    51    52    38    14     8     6     9     0     0   357
       17.0      8   111    85    43    44    29    21    10     6     1     0     0   358
       18.0     11   121    88    54    31    26    13     4     6     2     0     0   356
       19.0     15   125    74    63    25    17    19    11     4     2     1     0   356
       20.0     10   126    72    54    28    29    15     8     8     5     0     0   355
       21.0     16   106    76    39    38    27    17    18    14     3     2     0   356
       22.0     17   108    68    52    36    22    17    14    11     6     1     0   352
       23.0     20    98    77    50    30    29    16    13     8     9     1     0   351
       24.0     14    93    69    52    20    36    22    25    12     4     0     0   348
     TOTALS    343  2356  1796  1126   862   607   445   327   248   123    25     0

         45 SG1  VALUES LESS THAN   0.001               0 SG1  VALUES LARGER THAN  120.0
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TOWER SITE

FREQUENCY DISTRIBUTION OF SG3 VS HOUR SG3 RANGE 0.001 TO 120.0

ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

S G 3

		10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	TOTALS
	1.0	45	117	58	24	19	20	4	8	5	2	0	0	301
H	2.0	55	91	49	26	27	15	13	7	5	5	1	0	294
	3.0	44	106	52	31	21	14	12	8	1	3	0	0	294
O	4.0	51	109	48	23	22	16	7	8	2	1	0	0	287
	5.0	47	108	48	27	26	16	12	4	4	2	0	0	294
U	6.0	57	113	40	26	17	15	11	3	8	0	0	0	291
	7.0	42	128	39	31	14	12	8	10	4	3	0	0	291
R	8.0	35	110	48	36	16	13	11	13	4	4	0	0	290
	9.0	22	115	56	29	19	9	16	16	7	4	1	0	294
	10.0	22	99	67	30	22	19	18	11	8	5	1	0	302
	11.0	25	100	69	25	26	19	13	14	4	7	1	0	303
	12.0	18	100	77	36	25	16	11	10	10	4	0	0	307
	13.0	20	105	68	36	27	17	12	12	5	3	0	0	305
	14.0	10	98	71	40	29	19	19	7	7	3	1	0	304
	15.0	8	112	65	45	27	19	10	10	5	4	0	0	305
	16.0	15	111	68	56	25	14	5	4	3	7	0	0	309
	17.0	19	116	65	48	32	15	5	4	4	2	0	0	310
	18.0	22	136	77	34	22	9	5	4	3	0	1	0	313
	19.0	36	136	66	36	10	12	7	2	4	2	0	0	311
	20.0	54	124	61	26	19	7	4	8	7	0	0	0	310
	21.0	44	111	66	29	20	15	11	9	3	3	0	0	311
	22.0	42	113	59	30	14	16	13	10	7	4	0	0	308
	23.0	38	108	54	25	41	16	11	5	8	2	0	0	308
	24.0	44	104	59	32	12	20	18	7	6	3	0	0	304
	TOTALS	815	2670	1430	791	523	361	256	194	124	73	6	0	

44 SG3 VALUES LESS THAN 0.001 0 SG3 VALUES LARGER THAN 120.0

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                 MUNSEY  SITE

            FREQUENCY DISTRIBUTION OF  SG1  VS HOUR          SG1  RANGE    0.001 TO  120.0

                                                             ROW * COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                           S  G  1

                 10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 TOTALS
        1.0         2     4    32    29    46    92    81    58    50    35     9     1   439
  H     2.0         0    13    25    32    42    69    82    64    57    37    17     0   438
        3.0         2    17    26    28    38    65    73    62    60    50    15     0   436
  O     4.0         4    12    29    16    42    56    68    81    62    40    22     1   433
        5.0         0     6    30    25    42    45    62    77    74    51    20     1   433
  U     6.0         1     8    22    22    36    38    69    72    92    58    15     1   434
        7.0         0    10    27    16    32    50    47    82    77    68    24     1   434
  R     8.0         0    11    27    36    33    56    66    73    68    41    22     1   434
        9.0         0    19    36    62    51    70    67    43    46    30     8     0   432
       10.0         0    10    41    80    79    75    61    37    29    20     6     1   439
       11.0         0    13    49    52    67    88    61    42    40    15     4     0   431
       12.0         0    10    32    60    56    86    75    59    30    21     3     0   432
       13.0         0     5    38    41    72    73    74    63    47    20     4     0   437
       14.0         0     5    37    60    73    79    69    46    38    22     8     0   437
       15.0         1     5    38    61    77    62    75    51    46    23     4     0   443
       16.0         0     8    49    67    86    62    65    41    42    20     2     0   442
       17.0         0    15    64    68    67    68    58    49    29    19     3     0   440
       18.0         1    30    82    55    41    64    57    58    30    20     6     0   444
       19.0         9    42    88    52    47    48    55    54    29    15     2     0   441
       20.0        20    65    69    62    54    39    54    37    28    16     1     0   445
       21.0        19    55    72    58    53    54    50    43    25    10     6     0   445
       22.0         4    33    55    58    64    66    65    39    35    20     4     0   443
       23.0         3    18    44    53    69    59    67    53    38    32     7     0   443
       24.0         4    16    40    40    55    63    79    72    40    23     9     0   441
     TOTALS        69   430  1051  1133  1323  1527  1581  1356  1112   706   221     7

          5 SG1  VALUES LESS THAN   0.001               0 SG1  VALUES LARGER THAN  120.0
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                   CASTLE  SITE
             FREQUENCY DISTRIBUTION OF  SG1  VS HOUR          SG1  RANGE    0.001 TO  120.0
                                                              ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                              S  G  1

               10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 TOTALS
        1.0      0     8    27    34    41    33    41    32    33    21     7     0   277
 H      2.0      1     4    25    28    23    42    43    45    32    27     7     0   277
        3.0      1     4    20    34    34    36    40    38    36    27     3     0   273
 O      4.0      1     3    17    28    42    42    41    29    35    33     2     0   273
        5.0      0     5    13    36    40    43    34    22    48    22     6     0   269
 U      6.0      1     5    14    37    29    39    33    51    38    18     2     1   268
        7.0      0     4    21    34    30    36    38    28    41    26     4     0   262
 R      8.0      2     5    12    25    37    39    45    39    35    19     5     0   263
        9.0      0     6    24    29    40    38    33    24    43    20     5     0   262
       10.0      0     5    28    30    37    49    36    28    32    18     1     0   264
       11.0      1     7    22    41    46    31    39    34    26    18     1     0   265
       12.0      0     3    20    44    40    42    35    37    25    16     4     0   266
       13.0      0     3    24    25    31    49    45    42    23    22     5     0   269
       14.0      0     2    16    38    43    43    57    27    29    12     1     0   268
       15.0      0     0    16    35    49    42    61    34    21    11     2     0   271
       16.0      0     6    16    39    57    51    48    21    23    10     1     0   272
       17.0      1     1    16    33    63    54    40    31    20    13     1     0   273
       18.0      0     5    25    40    48    55    39    33    20    10     0     0   275
       19.0      0     7    29    51    42    38    44    34    20     9     0     0   274
       20.0      1     6    29    42    55    47    39    20    21    14     2     0   276
       21.0      0     6    28    39    51    47    36    28    30    12     0     0   277
       22.0      0     3    22    44    46    45    35    32    29    16     3     0   275
       23.0      1     5    18    44    40    33    52    30    24    25     4     0   276
       24.0      2     2    22    41    38    33    39    31    35    21     1     0   275
     TOTALS     12   105   504   871  1002  1017   991   770   720   440    67     1

          5 SG1  VALUES LESS THAN   0.001              0 SG1  VALUES LARGER THAN  120.0
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                        NASHS   SITE

                    FREQUENCY DISTRIBUTION OF  SG1  VS HOUR           SG1  RANGE    0.001 TO  120.0

                                                                      ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                               S  G  1

                 10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 TOTALS

         1.0        0    25    53    68    56    53    47    36    48    28    12     1   427

   H     2.0        0    23    57    55    63    36    50    47    47    39     9     0   426

         3.0        1    25    45    73    53    58    40    42    39    34    11     0   425

   O     4.0        1    29    55    56    51    57    55    52    37    26     7     0   426

         5.0        3    26    62    67    53    51    47    47    29    32     7     0   424

   U     6.0        1    31    55    77    44    49    60    40    34    28     5     0   424

         7.0        0    23    72    56    58    51    23    42    42    31    13     0   423

   R     8.0        2    29    52    68    50    62    27    43    44    33    12     0   422


         9.0        0    41    51    61    54    49    43    37    39    33    14     0   422

        10.0        0    37    72    55    65    50    50    36    26    26     9     0   426

        11.0        0    63    53    61    58    42    41    41    36    18     1     0   424

        12.0        3    57    81    34    53    40    44    35    24    16     7     0   425
        13.0        2    72    77    59    48    55    41    32    28    16     2     0   432

        14.0        0    63    66    63    59    51    44    27    28    10     3     0   430

        15.0        0    70    72    65    62    59    43    28    18    14     2     0   433

        16.0        2    61    65    68    77    45    32    25    21    13     3     0   437


        17.0        2    77    77    82    71    58    29    15    13     8     2     0   434

        18.0        1    77    89    94    69    40    24    15    10    13     2     1   435

        19.0        1    61    75    97    67    43    32    26    22     9     2     0   435

        20.0        1    39    49    74    58    64    35    42    40    28     6     1   437

        21.0        1    29    51    51    59    55    56    48    46    34     7     0   437

        22.0        0    17    48    60    62    41    52    51    52    42    10     0   435

        23.0        1    25    42    53    56    59    58    44    51    28     6     0   433

        24.0        1    26    40    67    61    63    35    41    50    34     7     1   432

      TOTALS       23  1042  1513  1816  1408  1237   998   892   824   593   159     4

            8 SG1  VALUES LESS THAN   0.001             1 SG1  VALUES LARGER THAN  120.0
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                    JOHNSN  SITE

                FREQUENCY DISTRIBUTION OF  SG1  VS HOUR          SG1  RANGE    0.001 TO  120.0

                                                                  ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                           S  G  1

                  10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 TOTALS
         1.0         5    74    35    31    21    24    23    13    13     6     1     0   246
  H      2.0         2    73    41    22    27    15    29    14    21     4     1     0   248
         3.0         3    74    46    19    19    17    22    21    19     5     0     0   245
  O      4.0         3    71    41    23    21    23    24    14    16     8     1     0   245
         5.0         4    68    40    24    16    22    20    27    13     9     0     0   243
  U      6.0         6    59    37    25    21    18    27    20    23     8     1     0   240
         7.0         4    58    54    21    17    18    21    26    18     6     0     0   243
  R      8.0         0    61    35    29    14    19    24    21    29    11     1     0   244
         9.0         3    57    43    18    25    29    18    25    22     5     1     0   247
        10.0         3    38    44    41    37    20    22    18    18     6     0     0   247
        11.0         2    36    50    33    26    27    36    17    15     6     0     0   248
        12.0         3    29    31    34    41    27    35    27    11     1     0     0   249
        13.0         4    25    37    39    33    39    32    24    12     5     0     0   249
        14.0         1    40    45    26    38    35    29    24    15     3     1     0   246
        15.0         1    25    30    54    33    38    34    26     6     2     1     0   250
        16.0         2    33    43    39    41    29    27    21    13     3     1     0   252
        17.0         3    38    31    59    20    29    25    14    12     2     0     0   252
        18.0         3    63    45    41    13    32    25    18     7     5     0     0   253
        19.0         4    62    50    28    22    18    26    19    16     8     0     0   253
        20.0         7    71    38    28    17    30    23    16    10    11     1     0   252
        21.0         5    73    36    26    26    17    35    13    10     8     1     0   250
        22.0         7    79    37    28    19    17    30    16    14     1     1     0   249
        23.0         4    72    39    26    24    22    21    19    14     8     0     0   249
        24.0         7    70    34    27    23    21    24    19    14     8     0     0   247
      TOTALS        85  1440   977   741   603   585   631   472   361   139    12     0

           4 SG1  VALUES LESS THAN    0.001             0 SG1  VALUES LARGER THAN  120.0
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                    TOWER   SITE
                FREQUENCY DISTRIBUTION OF  DT1  VS HOUR          DT1  RANGE   -2.200 TO    1.6
                                                                 ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                                D  T  1

                -2.0  -1.8  -1.6  -1.4  -1.2  -1.0  -0.8  -0.6  -0.4  -0.2   0.0   0.2   0.4   0.6   0.8   1.0   1.2   1.4   1.6 TOTAL
         1.0      0     0     0     1     2     3    10    33    38    26    99    27    22     3     1     0     0     0     0   265
   H     2.0      0     0     0     1     3     2    10    38    35    28    95    32    13     3     1     0     0     0     0   261
         3.0      0     0     0     1     2     5    18    37    44    32    85    31     9     1     0     0     0     0     0   265
   O     4.0      0     0     1     0     3     6    16    40    59    20    88    22     9     1     1     0     0     0     0   266
         5.0      0     0     1     1     3     7    15    48    55    21    84    21     5     0     0     1     0     0     0   262
   U     6.0      0     0     1     1     3    11    16    48    61    20    79    18     2     0     0     1     0     0     0   261
         7.0      0     0     1     0     6    16    17    69    45    15    78    12     1     0     1     0     0     0     0   261
   R     8.0      0     0     1     2     3    17    26    79    42    17    70     4     0     0     0     0     0     0     0   261
         9.0      0     1     1     0     7    19    26    73    50    25    52     2     0     0     1     0     0     0     0   257
        10.0      0     1     1     2    12    17    25    62    56    17    61     5     1     1     0     0     0     0     0   261
        11.0      0     0     2     1    11    19    28    85    42    14    49     5     2     0     0     1     0     1     0   260
        12.0      0     0     2     6    16    31    26    87    39    21    33     0     1     0     2     0     0     0     0   264
        13.0      1     1     9     3    41    41    22    72    43    13    17     0     0     0     0     0     1     0     0   264
        14.0      0     1     9     7    50    34    25    69    37    16    14     0     0     0     0     0     0     0     0   262
        15.0      1     0    11     5    41    37    24    73    35    13    20     0     0     0     0     0     0     0     0   260
        16.0      0     1     3     2    25    46    23    75    55    12    22     0     0     0     0     0     0     0     0   264
        17.0      0     1     0     0     7    19    20    84    61    20    47     2     0     0     0     0     0     0     0   261
        18.0      0     0     0     0     3     4    14    44    63    41    81     8     1     0     0     0     0     0     0   259
        19.0      0     0     1     0     1     3     7    27    33    42   133    15     1     2     0     0     0     0     0   265
        20.0      0     0     1     0     1     4     6    20    28    18   149    29     6     2     0     0     0     0     0   264
        21.0      0     0     0     0     2     3     6    18    32    25   116    38    21     4     0     0     0     0     0   265
        22.0      0     0     0     0     3     4     3    23    33    27   111    42    14     4     1     1     1     0     0   267
        23.0      0     0     0     1     2     3     4    26    39    25   107    26    21     5     4     1     0     0     0   264
        24.0      0     0     0     1     2     4     5    35    36    27    96    26    24     5     3     0     0     0     0   264
      TOTALS      2     6    45    35   249   355   392  1265  1061   535  1786   365   153    31    15     5     2     1     0

            0 DT1  VALUES LESS THAN  -2.200              1 DT1  VALUES LARGER THAN    1.6
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TOWER SITE

FREQUENCY DISTRIBUTION OF DT3 VS HOUR

DT3 RANGE -2.400 TO 3.3

ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

		D T 3																		
		-2.1	-1.8	-1.5	-1.2	-0.9	-0.6	-0.3	0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3 TOTAL
	1.0	0	0	0	0	0	0	8	23	21	54	37	23	35	32	29	16	11	3	4 283
H	2.0	0	0	0	0	0	0	1	27	17	53	35	33	29	28	20	18	8	3	4 276
	3.0	0	0	0	0	0	0	1	24	27	60	29	36	34	23	18	9	5	9	5 280
O	4.0	0	0	0	0	0	0	1	29	33	51	44	32	31	17	17	16	5	5	1 282
	5.0	0	0	0	0	0	0	2	32	38	52	41	28	26	27	10	9	9	3	1 278
U	6.0	0	0	0	0	0	0	4	40	35	55	32	42	25	18	8	8	8	3	1 279
	7.0	0	0	0	0	0	0	5	64	33	53	41	27	20	13	5	5	8	5	0 279
R	8.0	0	0	0	0	0	1	34	78	32	53	22	17	13	9	10	3	2	3	0 277
	9.0	0	0	0	0	4	17	50	92	27	36	16	8	13	6	1	2	1	0	1 274
	10.0	0	0	0	5	4	25	59	87	39	29	20	7	0	1	1	1	1	0	1 280
	11.0	0	1	3	2	11	43	62	90	27	29	8	2	0	0	0	1	0	0	0 279
	12.0	0	1	2	16	39	46	53	76	27	16	2	2	2	0	0	0	0	0	0 282
	13.0	0	2	12	40	47	40	42	67	18	10	2	1	0	1	0	0	0	0	0 282
	14.0	2	9	14	39	45	31	49	63	15	11	2	0	1	0	0	0	0	0	0 280
	15.0	2	7	16	40	35	38	46	63	18	8	3	1	1	0	0	0	0	0	0 278
	16.0	2	11	12	26	36	36	34	83	19	23	0	1	1	1	0	0	0	0	0 285
	17.0	0	4	13	13	19	39	43	67	34	40	7	1	1	0	0	0	0	0	0 281
	18.0	0	0	3	17	13	15	34	71	33	57	24	8	4	0	0	0	0	0	0 279
	19.0	0	1	0	1	8	17	17	53	43	74	41	13	10	4	1	0	3	0	0 286
	20.0	0	1	0	0	0	0	16	40	20	81	49	37	21	9	1	2	3	1	2 283
	21.0	0	0	0	0	0	0	0	24	23	76	43	41	25	13	13	11	6	4	3 282
	22.0	0	0	0	0	0	0	0	22	19	63	41	33	33	19	12	16	9	6	4 277
	23.0	0	0	0	0	0	0	1	22	16	61	30	34	23	19	24	17	20	6	5 278
	24.0	0	0	0	0	0	0	0	25	18	52	35	27	28	25	21	18	16	8	7 280
	TOTALS	6	37	75	199	261	448	553	1262	632	1097	599	454	376	265	191	152	115	59	39

1 DT3 VALUES LESS THAN -2.400 61 DT3 VALUES LARGER THAN 3.3

```
          TOWER   SITE

          FREQUENCY DISTRIBUTION OF  DT1  VS DT3             DT1  RANGE   -2.200 TO    1.6
                                                             DT3  RANGE   -2.600 TO    3.4
                                                             ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                          D  T  1

              -2.0  -1.8  -1.6  -1.4  -1.2  -1.0  -0.8  -0.6  -0.4  -0.2   0.0   0.2   0.4   0.6   0.8   1.0   1.2   1.4   1.6 TOTAL

     -2.3        0     0     0     0     3     2     0     0     0     0     0     0     1     0     0     0     0     0     0     6
 D   -2.0        0     0     0     1     6    14     0     1     0     0     0     0     0     0     0     0     0     0     0    22
     -1.7        0     1     6     3     2    16     8    19     1     0     0     0     0     0     0     0     0     1     0    57
 T   -1.4        0     1    11     6    28     1     4    48    10     0     2     0     0     0     0     0     0     0     0   111
     -1.1        0     0     8     5    50    33    10    30    49    13     3     0     0     0     0     0     0     0     0   201
 3   -0.8        2     1     4     2    32    40    30    40    32    41    40     0     0     0     1     0     0     0     0   265
     -0.5        0     0     6     5    28    40    37   125    26    15   119     1     0     0     0     0     0     0     0   402
     -0.2        0     2     3     7    35    33    36   175   115    13   158     3     1     0     0     0     0     0     0   581
      0.1        0     1     5     5    48   105   151   328   219    81   249    30     5     0     0     0     0     0     0  1228
      0.4        0     0     1     0     3    31    57   277   215   102   187    28    13     0     0     0     1     0     0   915
      0.7        0     0     0     0     4    10    23    57   154    68   243    31    16     8     1     1     0     0     0   616
      1.0        0     0     1     1     7    14    11    63    69    62   192    71    16     3     1     0     0     0     0   511
      1.3        0     0     0     0     1     7     9    45    48    34   162    65    20     1     2     0     0     0     0   394
      1.6        0     0     0     0     1     6     7    28    47    40   112    40    19     6     3     1     0     0     0   310
      1.9        0     0     0     0     1     1     3    13    28    22    89    26    18     6     2     0     1     0     0   210
      2.2        0     0     0     0     0     1     5     4    13    18    76    11     8     1     0     1     0     0     0   138
      2.5        0     0     0     0     0     0     0     7    21    12    75    16    13     1     0     1     0     0     0   146
      2.8        0     0     0     0     0     0     0     0     9     9    30    14     5     0     3     0     0     0     0    70
      3.1        0     0     0     0     0     0     1     3     2     2    21     3     6     0     0     0     0     0     0    38
      3.4        0     0     0     0     0     0     0     1     3     2    12     8     5     3     0     0     0     0     0    34
   TOTALS        2     6    45    35   249   355   392  1264  1061   534  1770   347   146    29    13     4     2     1     0

        0 DT1  VALUES LESS THAN  -2.200              1 DT1  VALUES LARGER THAN    1.6
        0 DT3  VALUES LESS THAN  -2.600             48 DT3  VALUES LARGER THAN    3.4
```

```
                    TOWER   SITE
                  FREQUENCY DISTRIBUTION OF  SE1  VS HOUR          SE1  RANGE    0.001 TO   48.0
                                                                   ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                            S  E  1

                  3.0   6.0   9.0  12.0  15.0  18.0  21.0  24.0  27.0  30.0  33.0  36.0  39.0  42.0  45.0  48.0 TOTALS
          1.0       8    34    59    23    17    28    10    10     1     0     0     0     0     0     0     0   190
  H       2.0      15    36    45    30    15    21    16     8     3     0     0     0     0     0     0     0   189
          3.0      10    47    44    19    20    24    16     4     3     1     0     0     0     0     0     0   188
  O       4.0      11    51    36    27    16    27    14     4     2     0     0     0     0     0     0     0   188
          5.0      16    49    42    24    13    16    18     6     0     0     0     0     0     0     0     0   184
  U       6.0      29    36    44    27    17    14     8     2     1     1     0     0     0     0     0     0   179
          7.0      19    32    42    29    21    16    12     5     1     0     0     0     0     0     0     0   177
  R       8.0       6    17    42    35    34    22    17     5     5     1     0     0     0     0     0     0   184
          9.0       1     7    37    32    24    34    28    14     6     3     1     1     0     0     0     0   188
         10.0       0     7    21    44    34    23    19    22    17     3     3     0     0     0     0     0   193
         11.0       0     1    21    43    33    35    21    13    11     7     2     0     1     0     0     0   188
         12.0       0     1    25    37    29    41    27    17    12     0     2     0     0     0     0     0   191
         13.0       0     2    26    36    33    31    35    15     9     1     1     1     1     0     0     0   191
         14.0       0     1    25    45    30    32    32    14     7     1     1     0     0     0     0     0   188
         15.0       0     5    36    35    23    41    26    15     5     3     0     1     0     0     0     0   190
         16.0       0     0    29    44    30    27    31    19     8     0     0     0     0     0     0     0   188
         17.0       0     5    40    34    43    25    18    20     4     0     1     0     0     0     0     0   190
         18.0       0    10    39    42    30    29    19    18     6     0     0     0     0     0     0     0   193
         19.0       1    12    43    37    35    27    17    15     2     2     1     0     0     0     0     0   192
         20.0       3    21    56    35    32    16    15    11     3     1     0     0     0     0     0     0   193
         21.0       5    28    57    31    26    23    20     3     3     0     0     0     0     0     0     0   196
         22.0       2    34    46    44    29    23     9     9     0     0     0     0     0     0     0     0   196
         23.0       2    30    49    45    27    16    16     6     3     0     1     0     0     0     0     0   195
         24.0       6    43    51    27    22    23    15     5     0     0     0     0     0     0     0     0   192
       TOTALS     134   509   955   925   633   614   459   260   112    24    13     3     2     0     0     0

             0 SE1  VALUES LESS THAN   0.001            0 SE1  VALUES LARGER THAN   48.0
```

```
                      TOWER   SITE

                   FREQUENCY DISTRIBUTION OF  SE3  VS HOUR          SE3  RANGE    0.001 TO   48.0

                                                                    ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                                     S  E  3

                  3.0   6.0   9.0  12.0  15.0  18.0  21.0  24.0  27.0  30.0  33.0  36.0  39.0  42.0  45.0  48.0 TOTALS

          1.0      14    55    45    22    28    16    11     7     2     2     1     1     0     0     0     0   204

   H      2.0      23    51    38    22    19    20    16     7     4     2     0     0     0     0     0     0   202

          3.0      15    62    29    10    20    20    23     9     9     2     0     1     0     0     0     0   200

   O      4.0      27    56    25    19    21    16    20    10     3     2     0     0     0     0     0     0   199

          5.0      30    46    37    20    16    14    17    11     4     2     0     0     0     0     1     0   198

   U      6.0      25    45    41    28    17    11    12    11     4     0     0     0     0     0     0     0   194

          7.0      22    41    41    23    14    22    15     6     4     3     1     1     1     0     0     0   194

   R      8.0       8    34    32    31    23    16     9    20     6     6     7     2     1     3     0     0   198

          9.0       4    12    24    36    28    27    16    17    13     9    12     4     0     0     0     0   202

         10.0       2     6    25    28    31    24    25    23    14    12     6     5     3     2     0     0   206

         11.0       0     4    19    31    29    32    25    24     9    13     8     7     1     1     0     0   203

         12.0       0     2    25    29    34    19    29    26    18    13     4     2     3     0     0     0   204

         13.0       0     0    19    36    29    21    39    19    24     8     5     2     0     2     1     1   206

         14.0       0     2    21    39    32    32    20    27    17     6     6     0     0     0     0     0   202

         15.0       0     2    25    33    31    30    29    26    16     8     2     0     2     0     0     0   204

         16.0       0     2    24    42    26    29    27    26    14    10     0     0     1     1     0     0   202

         17.0       0     4    32    43    26    27    28    22    14     5     1     1     0     0     0     0   203

         18.0       0     6    34    44    35    35    26    14     8     5     0     0     0     0     0     0   207

         19.0       3    15    42    39    33    24    25    15     7     1     1     1     0     0     0     0   206

         20.0       4    34    48    37    23    24    20    11     3     0     2     1     0     0     0     0   207

         21.0       3    50    41    40    23    21    17     8     5     2     0     0     0     0     0     0   210

         22.0       8    35    52    45    18    19    17     9     6     1     0     0     0     0     0     0   210

         23.0       9    40    63    30    21    16    16    11     2     1     0     0     0     0     0     0   209

         24.0      12    54    41    32    12    16    20     8     9     1     0     0     0     0     0     0   205

        TOTALS    208   658   824   759   589   511   502   367   215   114    56    28    12     9     2     1

             0 SE3  VALUES LESS THAN   0.001            3 SE3  VALUES LARGER THAN   48.0
```

```
                    TOWER   SITE

                    FREQUENCY DISTRIBUTION OF  SG1  VS DT1             SG1  RANGE     0.001 TO  120.0
                                                                       DT1  RANGE    -2.200 TO    1.8
                                                                       ROW * COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                                  S  G  1

                  10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 TOTALS
        -2.0        0     1     1     0     0     0     0     0     0     0     0     0     2
  D     -1.8        0     2     0     0     2     0     0     2     0     0     0     0     6
        -1.6        1    10     7     7     9     5     2     2     1     0     0     0    44
  T     -1.4        0     9     7    10     1     4     1     0     0     1     0     0    33
        -1.2        3    53    67    36    37    15    10   . 7     3     4     0     0   235
  1     -1.0       14    94    71    36    34    26    16    11     9     1     2     0   314
        -0.8       11   119    81    42    32    21    20     8     7     3     0     0   344
        -0.6       57   355   262   147   127    88    65    42    36    16     3     0  1198
        -0.4       41   324   237   127    86    69    46    46    29    11     0     0  1016
        -0.2       24   163   126    78    47    20    30     7     9     6     3     0   513
         0.0       68   526   366   246   180   124    81    75    46    27     6     0  1745
         0.2       22    81    71    46    41    29    19    17    16     5     4     0   351
         0.4        4    26    24    23    26    12     6     8     6     6     0     0   141
         0.6        1    15     4     2     0     1     1     1     1     2     0     0    28
         0.8        1     3     2     3     1     4     0     0     0     0     0     0    14
         1.0        0     0     3     1     0     0     0     1     0     0     0     0     5
         1.2        0     1     0     0     0     0     0     0     0     0     0     0     1
         1.4        0     0     0     0     1     0     0     0     0     0     0     0     1
         1.6        0     0     0     0     0     0     0     0     0     0     0     0     0
         1.8        0     0     0     0     0     0     0     0     0     0     0     0     0
       TOTALS     246  1784  1329   804   624   418   297   227   163    82    18     0
           45 SG1  VALUES LESS THAN   0.001            0 SG1  VALUES LARGER THAN  120.0
            0 DT1  VALUES LESS THAN  -2.200            1 DT1  VALUES LARGER THAN    1.8
```

```
                         TOWER   SITE

                       FREQUENCY DISTRIBUTION OF  SE3  VS SG3          SE3  RANGE    0.001 TO   48.0
                                                                       SG3  RANGE    0.001 TO  120.0
                                                                       ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERAVLS

                                  S  E  3

                    3.0   6.0   9.0  12.0  15.0  18.0  21.0  24.0  27.0  30.0  33.0  36.0  39.0  42.0  45.0  48.0 TOTALS

           10.0      60   118    94    34    26    17    14     6     1     0     0     0     0     0     0     0   370

   S       20.0      80   271   442   403   189   103    63    28     8     2     2     0     0     0     1     0  1592

           30.0      27   102   120   161   184   164   132    63    26    10     2     1     1     0     0     0   993

   G       40.0      15    56    48    48    73    98   112    83    34    14     4     0     0     1     0     0   586

           50.0       5    39    43    35    46    56    64    57    39    17     3     5     2     0     0     0   411

   3       60.0       5    27    22    21    37    18    30    51    41    20     8     2     4     0     0     0   286

           70.0       3    15    22    14     9    23    32    27    21    12    16     7     1     1     1     0   204

           80.0       1    13    12     8     9    14    24    23    17    16    10     3     0     1     0     0   151

           90.0       4     5     5    12     5    12    12    13    15     9     6     6     3     1     0     0   108

          100.0       1     3     6     5     1     5     5    10    12     8     4     3     0     2     0     0    65

          110.0       0     0     1     0     0     0     1     0     0     2     1     0     0     0     0     0     5

          120.0       0     0     0     0     0     0     0     0     0     0     0     0   . 0     0     0     0     0

         TOTALS     201   649   815   741   579   510   489   361   214   110    56    27    11     6     2     0

               0 SE3  VALUES LESS THAN   0.001             3 SE3  VALUES LARGER THAN   48.0
               7 SG3  VALUES LESS THAN   0.001             0 SG3  VALUES LARGER THAN  120.0
```

APPENDIX C

FREQUENCY DISTRIBUTIONS OF SO_2 AND NO_x VS. OBSERVED WINDS

This appendix presents 2-way joint frequencies of occurrence of classes of SO_2 or NO_x concentrations with wind directions observed at the Hockey site, 30 meter level (WD3).

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Page	Station	Parameters
289	Hockey	WD3 (10 to 180) vs. SO_2
290	Hockey	WD3 (190 to 360) vs. SO_2
291	Lambert	WD3 (10 to 180) vs. SO_2
292	Lambert	WD3 (190 to 360) vs. SO_2
293	Tower	WD3 (10 to 180) vs. SO_2
294	Tower	WD3 (190 to 360) vs. SO_2
295	Munsey	WD3 (10 to 180) vs. SO_2
296	Munsey	WD3 (190 to 360) vs. SO_2
297	Castle	WD3 (10 to 180) vs. SO_2
298	Castle	WD3 (190 to 360) vs. SO_2
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300	Nashs	WD3 (190 to 360) vs. SO_2
301	Johnson	WD3 (190 to 360) vs. SO_2
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306	Hockey	WD3 (190 to 360) vs. NO_x
307	Castle	WD3 (10 to 180) vs. NO_x
308	Castle	WD3 (190 to 360) vs. NO_x
309	Nashs	WD3 (10 to 180) vs. NO_x
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312	Tower	WD3 (190 to 360) vs. NO_x
313	Munsey	WD3 (10 to 180) vs. NO_x
314	Munsey	WD3 (190 to 360) vs. NO_x
315	Kents	WD3 (10 to 180) vs. NO_x
316	Kents	WD3 (190 to 360) vs. NO_x

```
                         HOCKEY  SITE

                 FREQUENCY DISTRIBUTION OF  WD3  VS SO2              WD3  RANGE     0.000 TO  180.0
                        FROM 76286 TO 77273                          SO2  RANGE     0.000 TO  500.0
                                                                     ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                           W  D  3

               10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 TOTALS

        5.0      96   103    74    70    61    55    50    67    73    93   103   102    75    59    55    55    90   113  1394

 S     10.0      19    15    18    22    16     9     8    25    27    21    14    18     9    12     8     8    10    25   284

       15.0       5     1     6     2     1     0     1     0     0     1     4     2     2     0     0     0     0     2    27

 O     20.0       4     6     5     3     3     0     2     2     1     0     0     0     0     1     0     0     1     1    29

       25.0       0     0     3     1     1     0     0     0     0     0     1     0     0     0     0     0     2     1     9

 2     30.0       0     2     0     5     3     2     1     1     0     0     0     0     0     1     0     0     0     0    15

       40.0       0     1     2     2     0     1     0     0     0     1     0     0     0     0     0     0     0     0     7

       50.0       0     0     1     0     0     1     0     0     0     1     0     1     0     0     0     0     0     0     4

       60.0       0     0     0     1     0     0     1     0     0     0     0     0     0     0     0     0     0     0     2

       80.0       0     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     0     1

      100.0       0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1

      150.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      200.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      300.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      500.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     TOTALS     124   128   110   106    85    68    63    95   101   117   122   123    87    73    63    63   103   142

           0 WD3  VALUES LESS THAN   0.000          5087 WD3  VALUES LARGER THAN  180.0
           0 SO2  VALUES LESS THAN   0.000             0 SO2  VALUES LARGER THAN  500.0
```

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```
                           HOCKEY  SITE

                 FREQUENCY DISTRIBUTION OF  WD3  VS SO2                WD3  RANGE  180.010 TO  360.0
                           FROM 76286 TO 77273                         SO2  RANGE    0.000 TO  500.0
                                                                       ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                           W  D  3

          190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

     5.0    140   175   273   332   495   322   170   158   151    95    88   102   135   213   188   154   135   140  3466
S   10.0     31    31    42    51    76    51    39    43    27    34    33    31    34    39    39    13    16    18   648
    15.0      6    22    16    27    36    26     7     7     1     6    10     4    16    21     9     3     2     3   222
O   20.0      0     4     5     9    27    15     3     6     5     1     1     4    10    18    12     3     2     1   126
    25.0      1     1     6    10    16    12     6     1     2     2     2     2     5    10     9     2     3     3    93
2   30.0      0     4     4     9    19    18     4     1     4     3     0     2     4    10     5     2     0     0    89
    40.0      1     0     1     6    12     6     0     1     4     2     1     2     2     7     1     1     0     1    48
    50.0      0     1     3     3    10     3     1     1     2     0     1     1     3     9     3     1     0     0    42
    60.0      0     0     2     4     9     4     3     0     0     0     2     1     2     3     1     0     0     0    31
    80.0      0     0     2     2     4     1     0     1     1     0     1     0     1     4     0     0     2     0    19
   100.0      0     0     0     0     0     0     0     2     1     0     0     1     1     4     0     0     0     0     9
   150.0      0     1     0     1     0     0     0     0     0     2     0     1     0     0     0     0     0     0     5
   200.0      0     0     0     0     0     0     0     1     0     0     0     0     0     0     0     0     0     0     1
   300.0      0     0     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     1
   500.0      0     0     0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     1
  TOTALS    179   239   354   454   704   459   233   222   198   145   139   151   213   339   267   179   160   166

     1823 WD3  VALUES LESS THAN 180.010               0 WD3  VALUES LARGER THAN  360.0
        0 SO2  VALUES LESS THAN   0.000               0 SO2  VALUES LARGER THAN  500.0
```

```
            FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS LAMBER SO2      WD3  RANGE     0.000 TO  180.0
                                                                    SO2  RANGE     0.000 TO  500.0
                                                                    ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                W  D  3

            10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 150.0 160.0 170.0 180.0 TOTALS

       5.0    68    65    49    47    36    31    25    56    49    60    58    74    49    86    42    73    86   954

 S    10.0     3     3     3     2     2     0     0     4     5     1     6     3     0     2     0     1     6    41

      15.0     0     2     0     0     0     0     0     0     0     1     2     1     0     0     0     1     0     7

 O    20.0     0     2     3     0     0     0     0     0     0     0     0     0     0     0     0     1     0     6

      25.0     0     0     1     0     0     0     0     0     0     0     1     0     0     0     0     0     0     2

 2    30.0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     0     0     1

      40.0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     0     0     1

      50.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      60.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      80.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     100.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     150.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     200.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     300.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     500.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

    TOTALS    71    72    56    49    38    31    25    60    54    62    69    78    49    88    42    76    92

        0 WD3  VALUES LESS THAN   0.000          4948 WD3  VALUES LARGER THAN  180.0
        0 SO2  VALUES LESS THAN   0.000             0 SO2  VALUES LARGER THAN  500.0
```

```
          FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS LAMBER SO2      WD3  RANGE  180.010 TO  360.0
                                                                  SO2  RANGE    0.000 TO  500.0
                                                                  ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                 W  D  3

          190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

     5.0    100   126   180   201   345   214   110   109    97    56    65    71   131   217   156   125   103    96  2502

S   10.0     10    11    17    19    34    38    17    15    18    12     8     4     7    31    13    11     9     7   281

    15.0      0     2     9     8    11     9     5     7     1     1     7     4     6     5    11     4     5     0    95

O   20.0      1     0     5     8    10     9     2     1     3     2     2     2     3    10    12     1     2     0    73

    25.0      0     3     6     7    18    13     1     1     2     2     1     0     4     7     2     4     0     0    71

2   30.0      0     0     0     5    12    11     0     1     3     0     2     1     3     3     5     1     2     1    50

    40.0      0     0     3     4    22    11     1     1     0     0     0     0     2     3     0     0     1     0    48

    50.0      0     1     1     1     4     3     5     3     1     1     0     3     1     0     0     0     1     0    25

    60.0      0     0     0     1     0     0     1     1     0     0     0     0     1     0     0     0     0     0     4

    80.0      0     0     0     0     1     1     0     0     0     0     2     0     0     0     0     0     0     0     4

   100.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

   150.0      0     0     0     0     0     1     0     0     0     0     0     0     0     1     0     0     0     0     2

   200.0      0     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     0     1

   300.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

   500.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

  TOTALS    111   143   221   254   457   310   142   139   125    74    87    85   159   277   199   146   123   104

     1733 WD3  VALUES LESS THAN 180.010              0 WD3  VALUES LARGER THAN  360.0
        0 SO2  VALUES LESS THAN   0.000              0 SO2  VALUES LARGER THAN  500.0
```

```
         FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS TOWER  SO2      WD3  RANGE    0.000 TO  180.0
                            FROM 76286 TO 77273                  SO2  RANGE    0.000 TO  500.0
                                                                 ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                     W  D  3

                 10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 150.0 160.0 170.0 180.0 TOTALS
        5.0      100   106    84    86    68    59    54    86    87   110    96   103    83   127    56    81   106   1492
 S     10.0        7     9     9     4     8     2     3     3     6     3     6    11     1     4     0    16    10    102
       15.0        0     2     0     0     0     0     0     2     0     0     3     0     1     1     1     1     0     11
 O     20.0        2     1     3     4     0     3     0     0     0     1     0     1     0     0     2     1     1     19
       25.0        1     1     1     0     1     1     0     0     0     0     0     1     0     0     0     2     2     10
 2     30.0        0     0     2     1     0     0     0     1     0     0     2     1     1     0     0     0     1      9
       40.0        1     0     1     3     0     1     0     0     0     0     2     1     0     1     0     0     0     10
       50.0        1     0     0     0     0           0     0     0     0     0     1     1     0     0     0     0      3
       60.0        0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     3      3
       80.0        0     0     0     0     0     0     0     0     2     0     0     0     0     1     0     0     0      3
      100.0        0     0     0     0     0     0     0     0     0     0     0     0     0     2     0     0     0      2
      150.0        0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0
      200.0        0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0
      300.0        0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0
      500.0        0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0
     TOTALS      112   119   100    98    77    65    57    92    95   114   109   119    87   136    59   101   123

           0 WD3  VALUES LESS THAN   0.000            5087 WD3  VALUES LARGER THAN  180.0
           0 SO2  VALUES LESS THAN   0.000               0 SO2  VALUES LARGER THAN  500.0
       FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS TOWER  SO2     WD3  RANGE  180.010 TO  360.0
                          FROM 76286 TO 77273                 SO2  RANGE    0.000 TO  500.0
                                                              ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                               W  D  3

              190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

       5.0     123   148   170   184   198   172   118   118   112    95    90    93   164   261   214   139   122   111   2622
  S   10.0      24    20    54    55    78    36    18    25    14    11     9    13    20    25    27    19    11    14    473
      15.0       4     8    25    24    43    31    14    11     5     5     3     9     5    11     6     3     2     1    211
  O   20.0       3     8    17    41    39    26    14     9    12     7     7     1     5     5     6     2     2     2    206
      25.0       1     7    10    20    41    17     8     8     3     4     3     3     1     4     0     0     1     2    133
  2   30.0       1     6     6    17    27    24     9     8     8     2     6     2     0     4     2     4     1     1    128
      40.0       2     6     8    18    40    25    16     7     2     5     6     7     5     2     3     0     3     0    155
      50.0       2     3     8    16    33    30     6     4     6     2     2     3     2     4     0     3     0     0    124
      60.0       1     3     3    12    29    20     6     3     6     2     1     2     1     2     0     1     0     1     93
      80.0       1     2     8    10    44    19     4     9     5     0     5     1     1     2     1     1     0     1    114
     100.0       1     1     2    11    28    11     1     2     2     4     2     3     1     2     0     0     1     0     72
     150.0       0     1     6     6    25    26     2     4     2     2     1     3     2     2     1     1     1     2     87
     200.0       0     0     1     2     9     6     0     0     2     2     2     2     1     2     0     1     0     1     31
     300.0       0     0     1     0     6     0     1     0     2     0     1     1     0     0     1     0     1     0     13
     500.0       0     0     0     0     2     1     0     0     0     0     0     0     0     0     0     0     0     0      3
    TOTALS     163   211   319   315   643   444   217   208   181   141   129   143   208   326   261   174   145   136

       1823 WD3  VALUES LESS THAN 180.010              0 WD3  VALUES LARGER THAN  360.0
          0 SO2  VALUES LESS THAN   0.000              0 SO2  VALUES LARGER THAN  500.0
```

```
              FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS MUNSEY S02     WD3  RANGE    0.000 TO  180.0
                          FROM 76286 TO 77273                        S02  RANGE    0.000 TO  500.0
                                                                     ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                  W  D  3

               10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 150.0 160.0 170.0 180.0 TOTALS

      5.0       105   111    96    88    76    63    58    91    99   114   115   119    83   131    59    95   131   1634

5    10.0        17    11    11    13     7     4     3     7     5     7     3     3     4     5     1     6     7    114

     15.0         1     2     2     1     2     0     1     0     1     1     1     1     3     2     0     0     1     19

0    20.0         1     2     3     1     1     0     0     0     0     1     3     3     0     0     0     0     0     15

     25.0         0     0     1     0     0     1     0     0     0     0     0     1     0     1     0     1     1      6

2    30.0         0     0     0     1     0     0     1     0     0     0     0     0     0     0     0     0     1      3

     40.0         0     0     0     1     0     1     0     0     0     0     2     1     1     0     1     0     0      7

     50.0         0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1      1

     60.0         0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     0      1

     80.0         0     0     0     0     0     1     0     0     0     0     0     0     0     0     0     0     0      1

    100.0         0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     0     0      1

    150.0         0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0

    200.0         0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0

    300.0         0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0

    500.0         0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0

   TOTALS       124   126   113   105    86    70    63    98   105   123   125   129    91   139    61   102   142

          0 WD3  VALUES LESS THAN   0.000           5087 WD3  VALUES LARGER THAN  180.0
          0 S02  VALUES LESS THAN   0.000              0 S02  VALUES LARGER THAN  500.0
```

```
                 FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS MUNSEY SO2      WD3  RANGE  180.010 TO  360.0
                               FROM 76286 TO 77273                       SO2  RANGE    0.000 TO  500.0
                                                                         ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                        W  D  3

                 190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

        5.0       157   205   300   343   506   359   201   205   172   122   122   133   171   244   186   151   138   140  3454
   S   10.0        14    15    30    61    93    62    22    14    20    15    11    12    22    41    39    22    22    18   533
       15.0         2     7    19    27    43    25    10     5     4     8     6     5     8    20    19     8     3     3   222
   O   20.0         2     1     7     9    25    18     5     6     4     4     2     3     4    13    11     1     3     4   122
       25.0         1     2     5     4    15    11     3     3     2     1     4     1     5     9    14     1     3     1    85
   2   30.0         0     2     0     6    15     6     2     2     0     0     1     1     1     8    10     2     0     1    57
       40.0         0     0     2     6     4     5     2     1     5     0     1     0     2     7     9     1     0     0    44
       50.0         0     1     0     3     5     1     1     2     1     1     0     0     0     3     2     1     0     0    21
       60.0         1     0     0     0     1     3     0     0     0     1     0     0     0     2     2     0     0     0    10
       80.0         0     1     1     1     3     1     0     0     2     1     0     0     1     1     0     0     0     1    13
      100.0         0     1     0     0     2     1     0     1     0     0     1     0     1     7     1     0     0     0    15
      150.0         0     1     0     0     1     0     0     0     0     0     0     1     1     0     0     1     0     0     5
      200.0         0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
      300.0         0     0     1     0     0     0     0     0     0     0     0     0     2     1     0     0     0     0     4
      500.0         0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1

     TOTALS       177   236   366   460   714   491   246   239   210   153   148   156   218   356   291   188   169   168

        1823 WD3  VALUES LESS THAN 180.010             0 WD3  VALUES LARGER THAN  360.0
           0 SO2  VALUES LESS THAN   0.000             0 SO2  VALUES LARGER THAN  500.0
```

```
FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS CASTLE SO2      WD3  RANGE     0.000 TO  180.0
                FROM 76286 TO 77273                     SO2  RANGE     0.000 TO  500.0
                                                        ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                               W  D  3

              10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 150.0 160.0 170.0 180.0 TOTALS

       5.0     47    50    34    32    22    14    16    28    30    25    28    35    28    59    31    52    75   606

S     10.0      3     3     4     2     0     3     1     3     3     5     5     5     4     1     1     0     1    44

      15.0      0     0     1     0     1     1     1     1     0     1     3     2     0     1     0     3     0    15

O     20.0      1     1     4     1     1     1     0     0     1     1     2     2     1     2     0     0     3    21

      25.0      0     0     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     1

2     30.0      0     0     0     0     0     0     0     0     0     1     2     0     0     0     0     0     0     3

      40.0      1     1     0     1     1     0     0     1     0     0     0     3     1     1     0     0     0    10

      50.0      0     0     0     1     1     1     0     0     0     0     0     0     0     0     0     0     0     3

      60.0      0     0     0     1     0     0     0     2     0     0     0     0     0     1     0     0     0     4

      80.0      0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1

     100.0      1     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     2

     150.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     200.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     300.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     500.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

    TOTALS     53    55    45    38    26    20    18    35    34    33    40    47    34    66    32    55    79

        0 WD3  VALUES LESS THAN   0.000           5087 WD3  VALUES LARGER THAN  180.0
        0 SO2  VALUES LESS THAN   0.000              0 SO2  VALUES LARGER THAN  500.0
```

```
                FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS CASTLE SO2      WD3  RANGE  180.010 TO  360.0
                                FROM 76286 TO 77273                     SO2  RANGE    0.000 TO  500.0
                                                                        ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                                      W  D  3

                190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

         5.0      65    98   144   161   244   192    93    91    60    38    43    44    83   180   134    60    60    58  1848

  S     10.0       4     5    31    38    42    31     9     6    10     2     2     7    10    16    27    12    10     4   266

        15.0       2     6    14    15    24    19    10     1     4     4     4     2     1     7     2     3     2     1   121

  O     20.0       2     0     6     7    27    14     2     1     0     0     0     3     1     5     4     1     3     1    77

        25.0       1     1     4     8    26    14     1     1     3     0     0     1     0     2     2     1     1     0    66

  2     30.0       1     1     1     4    10     9     2     2     1     0     0     0     2     3     1     0     2     0    39

        40.0       1     0     0     4     8     4     1     1     1     3     0     0     0     1     0     1     0     0    25

        50.0       0     0     0     2     6     4     0     0     2     0     0     0     0     1     1     0     0     0    16

        60.0       0     0     0     2     2     1     0     0     1     0     1     1     0     0     0     0     0     0     8

        80.0       0     1     0     0     2     1     0     0     0     0     0     0     0     0     0     0     0     0     4

       100.0       0     0     0     0     0     0     0     0     1     0     0     0     0     1     1     0     0     0     3

       150.0       1     0     0     2     3     1     0     1     0     0     0     0     0     1     0     0     0     1    10

       200.0       0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1

       300.0       0     0     1     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     2

       500.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      TOTALS      77   113   201   244   394   290   118   104    83    47    50    58    97   217   172    78    79    65

          1823 WD3  VALUES LESS THAN 180.010               0 WD3  VALUES LARGER THAN  360.0
             0 SO2  VALUES LESS THAN   0.000               0 SO2  VALUES LARGER THAN  500.0
```

```
                FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS NASHS  SO2      WD3  RANGE     0.000 TO  180.0
                               FROM 76286 TO 77273                      SO2  RANGE     0.000 TO  500.0
                                                                        ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                        W  D  3

                10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 150.0 160.0 170.0 180.0 TOTALS

          5.0    111   110    91    81    71    65    56    89    94   106    96   100    76   101    51    96   115  1509

   S     10.0      9     9     8    21    10     1     3     9     7     9    18    19    11    23     9     7    10   183

         15.0      1     2     2     0     1     1     0     0     0     0     1     0     0     1     0     0     0     9

   O     20.0      1     2     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     3

         25.0      0     0     1     0     0     2     0     0     0     0     0     0     0     1     0     0     0     4

   2     30.0      0     0     0     1     0     0     0     0     1     0     0     0     0     0     0     0     0     2

         40.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

         50.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

         60.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1     1

         80.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

        100.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

        150.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

        200.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

        300.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

        500.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

       TOTALS    122   123   102   103    82    69    59    98   102   115   115   119    87   126    60   103   126

             0 WD3  VALUES LESS THAN    0.000           5087 WD3  VALUES LARGER THAN  180.0
             0 SO2  VALUES LESS THAN    0.000              0 SO2  VALUES LARGER THAN  500.0
```

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```
          FREQUENCY DISTRIBUTION OF HOCKEY WD1 VS NASHS  SO2      WD1  RANGE  180.010 TO  360.0
                                                                  SO2  RANGE    0.000 TO  500.0
                                                                  ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                  W  D  1

          190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

     5.0   157   175   255   336   462   318   143   164   123   103    97   112   160   255   212   141   138   141   3512
 S  10.0     4    11    57    53    89    51    30    22    31    20    24    25    31    46    37    24    10    13    608
    15.0     2     2     5    14    22    12     4     7     6     0     4     0     1     2     3     2     5     2     93
 O  20.0     0     0     4     6    23    15     1     5     2     4     6     1     1     3     1     1     2     2     77
    25.0     0     1     0     1     9     9     2     4     1     2     1     1     0     0     2     2     1     2     38
 2  30.0     0     0     2     1     7     6     2     0     1     2     0     2     0     1     2     0     0     0     26
    40.0     1     1     2     2     6     5     3     3     1     1     1     2     1     1     0     0     0     0     30
    50.0     0     1     2     1     5     4     1     0     6     0     0     1     1     0     0     0     0     1     26
    60.0     0     0     0     0     2     1     0     0     0     0     0     1     0     0     0     0     0     0      4
    80.0     0     0     0     0     2     1     0     0     1     2     1     0     1     0     0     0     0     0      8
   100.0     0     0     0     0     0     0     0     0     0     0     0     0     0     3     0     0     0     0      3
   150.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0
   200.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0
   300.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0
   500.0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      0

  TOTALS   165   210   427   414   647   426   195   205   172   134   134   145   196   311   257   170   156   161

      2143 WD1  VALUES LESS THAN 180.010                   0 WD1  VALUES LARGER THAN  360.0
         0 SO2  VALUES LESS THAN   0.000                   0 SO2  VALUES LARGER THAN  500.0
```

```
              FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS JOHNSN SO2     WD3  RANGE  180.010 TO  360.0
                                                                      SO2  RANGE    0.000 TO  500.0
                                                                      ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                 W  D  3

              190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

       5.0     106   108   164   160   283   169   103   101    88    60    55    67   131   195   120   110    68    61  2159

 S    10.0      19    42    43    56    86    58    30    32    31    23    28    25    31    21    33    21    21    28   630

      15.0      18    20    40    56    69    55    30    19    15    15    16    10     7    16    18    11    14    11   440

 O    20.0       9    16    15    19    23    21    13    11    14    11     4    14     9    10     8    12     2    11   222

      25.0       1     5     2     7    18     8     6     7     4     6     2     4     3     2     1     0     5     1    82

 2    30.0       1     3     2     4    12     5     2     7     4     2     1     0     0     0     1     1     2     3    50

      40.0       2     0     1     5     9     7     3     1     1     3     0     4     0     6     3     0     1     1    47

      50.0       0     2     4     8     7     2     1     2     3     1     0     1     0     0     2     1     0     1    35

      60.0       0     0     0     0     2     1     0     0     1     0     0     0     1     1     1     0     0     0     7

      80.0       0     1     0     1     5     3     2     0     0     3     0     0     1     5     3     0     1     2    27

     100.0       0     0     0     1     2     4     2     0     0     0     0     1     1     2     0     0     0     1    14

     150.0       0     0     0     0     0     1     0     1     1     0     1     0     2     3     0     0     1     1    11

     200.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1     0     1

     300.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     1

     500.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

    TOTALS     156   197   271   317   516   334   192   181   162   124   117   126   188   261   191   156   116   121

       1603 WD3  VALUES LESS THAN 180.010                 0 WD3  VALUES LARGER THAN  360.0
          0 SO2  VALUES LESS THAN   0.000                 0 SO2  VALUES LARGER THAN  500.0
```

```
FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS JOHNSN SO2     WD3  RANGE     0.000 TO  180.0
                                                       SO2  RANGE     0.000 TO  500.0
                                                       ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                          W  D  3

              10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 140.0 150.0 160.0 170.0 180.0 TOTALS

       5.0     28    36    36    33    32    33    28    58    48    74    73    70    52    89    43    80   101   914

  S   10.0     17    14    16    12     7     7     9     6    18    16    17    14    14    11     7    13    15   213

      15.0      9     7     6     9    12     8    10     9    13     9     7    15    10    15     8     3     8   158

  O   20.0     10     9     7     4     6     3     4     1     3     4     3     5     1     8     3     1     3    75

      25.0      2     2     3     0     1     3     1     3     2     1     0     1     0     1     0     1     1    22

  2   30.0      1     1     2     0     1     0     0     1     0     2     0     0     0     0     0     0     0     8

      40.0      5     6     4     3     2     2     0     0     1     0     1     0     1     0     0     1     0    26

      50.0      3     1     2     2     0     0     1     0     0     1     0     1     0     0     0     0     0    11

      60.0      1     1     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     3

      80.0      0     3     0     0     0     0     0     0     0     1     0     1     0     0     0     0     1     6

     100.0      2     1     2     0     0     0     0     0     0     0     0     0     0     0     0     0     0     5

     150.0      1     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     2

     200.0      1     1     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     3

     300.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     500.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

    TOTALS     80    83    80    63    61    56    53    79    85   108   101   107    78   124    61    99   129

         0 WD3  VALUES LESS THAN   0.000          4780 WD3  VALUES LARGER THAN  180.0
         0 SO2  VALUES LESS THAN   0.000             0 SO2  VALUES LARGER THAN  500.0
```

```
                FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS KENTS  S02      WD3  RANGE    0.000 TO  180.0
                          FROM 76286 TO 77273                           S02  RANGE    0.000 TO  500.0
                                                                        ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                   W  D  3

                10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 150.0 160.0 170.0 180.0 TOTALS

         5.0     105   113    98    96    78    64    57    95   100   112   110   114    84   131    62   102   135  1660
  S     10.0       6     4     3     2     0     0     0     0     0     1     0     1     1     0     0     1     1    20
        15.0       0     0     0     0     0     1     0     0     0     2     0     1     0     0     0     1     0     5
  O     20.0       1     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     2
        25.0       0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     1
  2     30.0       0     0     0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     1
        40.0       0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     1
        50.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
        60.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
        80.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
       100.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
       150.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
       200.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
       300.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
       500.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
      TOTALS     112   118   101   100    78    70    57    95   100   115   110   116    85   131    62   104   136

              0 WD3  VALUES LESS THAN   0.000          5087 WD3  VALUES LARGER THAN  180.0
              0 S02  VALUES LESS THAN   0.000             0 S02  VALUES LARGER THAN  500.0
```

```
             FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS KENTS  SO2      WD3  RANGE  180.010 TO  360.0
                             FROM 76286 TO 77274                     SO2  RANGE    0.000 TO  500.0
                                                                     ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                     W  D  3

            190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

      5.0    174   227   327   398   579   398   202   203   178   124   133   135   200   339   255   170   142   147  4331

S    10.0      1     2     2     6    27    17     5     4     7     2     6     4     6     3     6     3     9     8   118

     15.0      0     1     5     4    19     8     3     4     3     7     0     3     6     4     6     4     0     1    78

O    20.0      0     1     2     5    12     9     4     1     1     0     0     2     0     1     2     2     3     2    47

     25.0      0     0     4     1     6     3     2     2     3     0     0     0     0     1     2     1     1     0    26

2    30.0      0     0     1     1     0     2     2     2     1     1     0     0     0     4     2     0     0     0    16

     40.0      0     0     2     3     5     7     2     3     1     0     0     0     0     0     1     0     0     0    24

     50.0      0     0     0     2     6     5     1     1     0     0     1     0     0     0     0     0     0     0    16

     60.0      0     0     0     2     2     3     2     0     1     0     0     0     0     0     0     0     0     0    10

     80.0      0     0     0     2     2     1     0     0     0     0     0     0     0     0     0     0     0     0     5

    100.0      0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1

    150.0      0     0     0     0     1     1     0     0     0     0     0     0     0     0     0     0     0     0     2

    200.0      0     0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     1

    300.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

    500.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

   TOTALS    175   231   343   425   660   451   223   220   195   134   140   144   212   352   274   180   155   158

       1823 WD3  VALUES LESS THAN 180.010               0 WD3  VALUES LARGER THAN  360.0
          0 SO2  VALUES LESS THAN   0.000               0 SO2  VALUES LARGER THAN  500.0
```

```
                    HOCKEY  SITE

        FREQUENCY DISTRIBUTION OF  WD3  VS NOX           WD3  RANGE    0.000 TO  180.0
                   FROM 76324 TO 77273                    NOX  RANGE    0.000 TO  500.0
                                                          ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                    W  D  3

           10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 TOTALS

     5.0     71    78    69    57    56    51    47    64    73    91    86   101    67    51    46    50    75    93  1226
N   10.0      7     8     5     6     6     3     5     8     8     9    10     6     9     7     5     3     9     5   119
    15.0      0     2     3     2     1     0     0     2     1     3     1     2     4     3     2     2     1     2    31
O   20.0      1     1     0     0     0     0     3     1     2     2     0     0     0     0     0     0     1     1    12
    25.0      0     0     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     1
X   30.0      0     0     0     1     1     0     0     0     0     0     1     1     1     0     0     0     0     0     5
    40.0      1     0     3     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     5
    50.0      1     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     1     3
    60.0      0     0     1     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     2
    80.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
   100.0      0     0     0     0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     1
   150.0      0     0     1     0     0     0     0     0     0     0     0     0     1     0     0     0     0     0     2
   200.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
   300.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
   500.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  TOTALS     81    89    82    67    64    55    56    75    84   105    98   110    82    63    53    55    86   102

        0 WD3  VALUES LESS THAN   0.000          4761 WD3  VALUES LARGER THAN  180.0
        0 NOX  VALUES LESS THAN   0.000             1 NOX  VALUES LARGER THAN  500.0
```

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```
                    HOCKEY  SITE

           FREQUENCY DISTRIBUTION OF  WD3  VS NOX          WD3  RANGE  180.010 TO  360.0
                    FROM 76324 TO 77273                    NOX  RANGE    0.000 TO  500.0
                                                           ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                            W  D  3

               190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

        5.0      117   152   228   252   382   259   129   124   102    73    58    56    43   105    99    92    85    97  2453

 N     10.0        8    25    34    50    71    37    27    21    24    13    23    28    32    36    21    23    12    12   497

       15.0        4     5     8     4    14    22    15    16    11    14     7    14    22    30    23    12     9     6   236

 O     20.0        2     0     4     6     7     4     4     3     2     8     6     6    16     7     6     6     1     2    90

       25.0        0     2     1     0     3     0     2     5     1     1     6     5    10     6     3     0     0     0    45

 X     30.0        0     0     0     1     1     0     0     2     2     2     2     2    11     4     4     2     0     0    33

       40.0        0     1     0     0     1     1     1     1     1     0     3     3    13     6     3     3     0     0    37

       50.0        1     0     0     0     0     0     1     0     4     2     3     2     5     4     0     1     0     0    23

       60.0        0     0     1     0     0     0     1     0     0     1     1     0     5     1     1     0     1     0    12

       80.0        0     0     0     0     1     0     0     4     2     1     2     1     3     7     2     1     0     1    25

      100.0        0     0     0     0     0     0     0     0     0     0     3     2     2     2     0     2     1     0    12

      150.0        0     0     0     1     0     0     0     0     1     1     2     2     2     0     0     0     1     0    10

      200.0        0     1     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     2

      400.0        0     0     0     0     0     0     0     0     0     1     0     0     0     0     0     0     0     0     1

      500.0        0     1     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     2

     TOTALS      132   187   276   315   480   323   180   176   150   117   116   121   164   209   162   142   110   118

        1568 WD3  VALUES LESS THAN 180.010             0 WD3  VALUES LARGER THAN  360.0
           0 NOX  VALUES LESS THAN   0.000             1 NOX  VALUES LARGER THAN  500.0
```

```
          FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS NASHS  NOX      WD3  RANGE     0.000 TO  180.0
                          FROM 76324 TO 77273                     NOX  RANGE     0.000 TO  500.0
                                                                  ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                   W  D  3

                10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 150.0 160.0 170.0 180.0 TOTALS

        5.0      53    51    39    29    29    22    21    23    26    44    46    39    47    66    33    47    60   675

  N    10.0      13    16    13    17     8     9     5    13    13    17    12    16     6    22     6    25    26   237

       15.0       6     4    10     5     9     9     9     9    12    17    13    10    10     8     5     6    13   155

  O    20.0       4     6     4     3     9     4     3     8     7     9     9     8     9    10     5     7     8   113

       25.0       0     3     3     4     2     4     1     8    12     6     9    10     1     3     7     5     8    86

  X    30.0       2     3     5     0     1     1     1     5     3     5     3     7     1     1     2     5     3    48

       40.0       1     3     2     1     3     2     3     6     7     7     5    12     3     8     1     2     3    69

       50.0       2     4     2     3     0     5     3     1     4     2     3     0     1     5     0     2     2    39

       60.0       0     0     3     1     0     1     4     3     1     1     2     2     2     2     1     0     1    24

       80.0       1     1     1     2     2     1     2     1     2     2     1     4     0     0     1     0     0    21

      100.0       0     0     1     0     0     0     1     2     0     1     0     1     0     0     0     0     0     6

      150.0       0     0     1     1     0     0     0     0     0     0     0     1     0     0     0     0     0     3

      200.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      300.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      500.0       0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     TOTALS      82    91    84    66    63    58    51    73    87   111   103   110    90   125    51    99   124

            0 WD3  VALUES LESS THAN   0.000          4761 WD3  VALUES LARGER THAN  180.0
            0 NOX  VALUES LESS THAN   0.000             2 NOX  VALUES LARGER THAN  500.0
```

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```
FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS NASHS  NOX     WD3  RANGE  180.010 TO  360.0
                                                       NOX  RANGE    0.000 TO  500.0
                                                       ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS

                           W  D  3

          190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

     5.0     71    62    84    92   167    91    44    37    46    34    45    55   123   229   147   110    80    88  1605
N   10.0     34    45    50    71   120    72    37    42    26    16    28    32    35    41    40    20    17    19   745
    15.0     19    29    41    36    78    50    33    28    30    24    16    14    12    11     9    13    13     8   483
O   20.0     17    19    25    43    53    45    27    26    21    13     9    17    12    10     5     6     1     2   346
    25.0      5    12    24    35    43    31    16    15    16     9     8     3     4     7     8     5     1     1   242
X   30.0     10     9    14    23    27    31    14    20    16    11     7     3     4     7     4     3     5     2   209
    40.0     10    11    34    28    36    23    16    21    13     8     9     7     9     3     2     3     2     2   237
    50.0      3     7    15    13    16    16     9     7     6    10     4     5     2     3     0     6     2     0   125
    60.0      0     6     5     4     9    17     7     7     6     4     4     2     4     2     2     0     1     1    81
    80.0      3     5     7    11    17    13    11     5     7     3     3     2     0     1     1     0     1     0    90
   100.0      2     2     2     5     6     9     1     3     3     1     1     1     1     1     1     0     1     3    43
   150.0      1     0     0     3     5     1     1     2     1     1     2     1     1     2     0     0     0     0    24
   200.0      0     1     0     0     0     1     0     0     0     1     0     0     0     0     0     0     0     0     3
   300.0      0     0     0     0     1     2     0     0     1     0     1     1     0     0     0     0     0     0     6
   500.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

 TOTALS     171   207   400   374   500   314   216   213   192   135   137   143   207   317   219   166   124   126

   2493 WD3  VALUES LESS THAN 180.010             0 WD3  VALUES LARGER THAN  360.0
      0 NOX  VALUES LESS THAN   0.000             2 NOX  VALUES LARGER THAN  500.0
```

```
       FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS CASTLE NOX     WD3  RANGE     0.000 TO  180.0
                     FROM 76324 TO 77273                      NOX  RANGE     0.000 TO  500.0
                                                              ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                          W  D  3

              10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 150.0 160.0 170.0 180.0 TOTALS
        5.0     3     1     0     0     0     0     0     0     0     1     3     1     1     6    11    17    19    63
  N    10.0     3     6     4     1     3     0     0     1     1     1     0     7     5     9     6    10    11    68
       15.0     3     3     3     0     1     3     1     1     1     1     1     3     2     4     2     4     6    39
  O    20.0     0     2     1     0     0     1     2     2     4     6     1     2     2     5     0     0     1    29
       25.0     1     2     1     0     1     0     1     1     0     0     1     6     1     0     0     2     2    19
  X    30.0     0     1     2     0     0     0     1     1     2     1     2     2     0     1     2     0     1    16
       40.0     0     1     0     0     0     0     0     1     0     2     1     3     3     1     0     2     3    17
       50.0     2     2     4     1     1     0     1     0     1     2     2     3     0     4     1     1     3    28
       60.0     0     1     1     1     1     1     2     3     1     0     0     2     1     3     0     0     2    19
       80.0     0     1     0     1     0     2     1     0     1     2     3     4     2     4     0     0     2    23
      100.0     0     0     1     1     0     0     0     0     0     1     5     1     0     0     0     2     0    11
      150.0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     1     2
      200.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
      300.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
      500.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     TOTALS    12    20    18     5     7     7     9    10    11    17    19    34    17    37    22    38    51

           0 WD3  VALUES LESS THAN   0.000          4761 WD3  VALUES LARGER THAN  180.0
           0 NOX  VALUES LESS THAN   0.000             1 NOX  VALUES LARGER THAN  500.0
```

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```
             FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS CASTLE NOX      WD3  RANGE  180.010 TO  360.0
                           FROM 76324 TO 77273                       NOX  RANGE    0.000 TO  500.0
                                                                     ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                      W  D  3

             190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

        5.0     15    10     5     9    39     8     5    20    11     2     7    12    34    70    47    23    15    12   343

  N    10.0      8     7    14    19    39    28    14     8     4     4     2     5    17    24    25     7    10     9   244

       15.0      6     7    18    12    29    21    10     6     3     3     2     4     0     8     9     6     4     0   148

  O    20.0      2     9    18     6    16    14     7     7     5     3     3     5     3     3     5     3     0     1   110

       25.0      2     3     9    10    11    17     3     3     6     1     3     0     2     3     1     1     1     1    77

  X    30.0      1     5     6     8    10     9     8     5     3     1     2     1     2     3     1     1     1     0    67

       40.0      2     5    16    14    16    23     9     4     4     0     1     0     3     3     1     1     3     1   103

       50.0      2     5     9    12    15    14     7     1     1     1     1     1     1     0     1     0     1     2    74

       60.0      1     7     7     7    15    10     3     1     3     0     0     0     1     0     0     0     1     0    56

       80.0      3     5    11    16    16    13     5     1     0     1     0     2     0     2     0     0     0     1    76

      100.0      3     5     5     9     8     8     1     2     0     2     0     0     2     0     1     0     0     0    46

      150.0      1     0     2     5     3     2     0     0     2     0     1     0     0     0     1     0     0     0    17

      200.0      1     0     1     1     1     1     0     0     0     0     0     0     0     0     1     0     0     0     6

      300.0      0     1     0     0     2     1     0     0     0     0     0     0     0     0     0     0     0     0     4

      500.0      0     0     0     1     3     1     0     0     0     0     0     0     0     0     0     0     0     0     5

     TOTALS     47    69   121   129   223   167    72    58    42    18    22    30    64   116    93    42    36    27

        1568 WD3  VALUES LESS THAN 180.010            0 WD3  VALUES LARGER THAN  360.0
           0 NOX  VALUES LESS THAN   0.000            1 NOX  VALUES LARGER THAN  500.0
```

```
FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS TOWER NOX     WD3  RANGE    0.000 TO  180.0
                 FROM 76324 TO 77273                  NOX  RANGE    0.000 TO  500.0
                                                      ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                         W  D  3

                10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 150.0 160.0 170.0 180.0 TOTALS

         5.0     51    45    45    33    38    24    24    27    37    45    48    59    46    63    39    61    65   750

  N     10.0     18    22    17    13    13    16    16    30    25    35    28    23    12    25     7    17    20   337

        15.0      6    12     7     9     8     7     4     4     9    14    10    11     8    19     5     4     4   141

  O     20.0      2     4     7     3     1     3     4     6     6     7     2     4     2     7     3     4     8    73

        25.0      3     4     3     5     0     3     0     3     1     3     2     2     6     3     2     2     5    47

  X     30.0      1     1     1     0     1     0     0     1     0     1     3     1     0     1     0     3     4    18

        40.0      0     2     2     1     0     1     3     3     2     0     1     3     2     1     1     2     6    30

        50.0      2     0     1     0     0     0     0     1     3     0     9     7     4     5     1     3     1    37

        60.0      0     0     0     0     0     0     0     0     0     1     2     1     2     1     0     0     4    11

        80.0      0     0     2     0     1     1     0     0     0     1     3     3     0     0     0     2     1    14

       100.0      0     0     0     0     0     0     0     0     0     0     1     2     0     0     0     2     1     6

       150.0      0     0     0     0     0     0     0     0     0     0     1     1     1     1     0     0     1     5

       200.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     2     2

       300.0      0     0     0     0     0     0     0     0     1     0     0     0     0     0     0     0     0     1

       500.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      TOTALS     83    90    95    64    62    55    51    75    84   107   110   117    83   126    58   100   122

          0 WD3  VALUES LESS THAN   0.000         4761 WD3  VALUES LARGER THAN  180.0
          0 NOX  VALUES LESS THAN   0.000            1 NOX  VALUES LARGER THAN  500.0
```

```
              FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS TOWER  NOX       WD3  RANGE  180.010 TO  360.0
                           FROM 76324 TO 77273                         NOX  RANGE    0.000 TO  500.0
                                                                       ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                  W  D  3

               190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

        5.0      56    53    55    55    55    42    30    29    42    36    31    45    95   127    95    91    64    75  1076

 N     10.0      27    40    39    48    45    35    38    36    23    25    23    18    31    60    45    23    25    16   597

       15.0      23    31    48    37    68    39    29    25    28    12    10    14    24    21    30    27    12     6   484

 O     20.0      13    14    31    31    41    25    16    18    16    13    12     4     9    25    19     8     7     7   309

       25.0       7    18    24    19    43    21     8    14     4     8     5     9     5    10    22     7     6     2   232

 X     30.0       5    10    18    14    19    17     9     9    10     9     8     7     9    18    13     5     5     1   186

       40.0       7    14    21    28    47    28    13    11    12     5    10    10     7    10    14     4     3     3   247

       50.0       4     6    15    26    39    26    12    23     8    10     4     2     4     7     6     2     4     3   201

       60.0       5     2    11    28    42    32    12     8     8     3     4     6     4     5     0     3     1     2   176

       80.0       3     7    12    37    57    43    12    10     9     5     6     6     3     6     2     4     1     0   223

      100.0       1     4    11    24    36    33     9     7     3     3     4     6     3     4     0     0     0     1   149

      150.0       5     5    16    24    58    28    14    10     6     2     7     3     3     2     1     0     0     2   186

      200.0       1     2     6    12    32    27     6     3     3     4     1     1     0     0     0     1     0     1   100

      300.0       0     1     4     5    31    15     3     3     7     0     3     2     1     4     1     0     0     1    81

      500.0       0     0     1     1     5    12     1     1     2     0     0     0     0     0     0     0     0     0    23

     TOTALS     157   207   312   389   618   423   212   207   181   135   128   133   198   299   248   175   129   120

         1558 WD3  VALUES LESS THAN 180.010                0 WD3  VALUES LARGER THAN  360.0
            0 NOX  VALUES LESS THAN   0.000                1 NOX  VALUES LARGER THAN  500.0
```

```
          FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS MUNSEY NOX     WD3  RANGE    0.000 TO  180.0
                      FROM 76324 TO 77273                        NOX  RANGE    0.000 TO  500.0
                                                                 ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                             W  D  3

          10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 150.0 160.0 170.0 180.0 TOTALS

     5.0    69    69    64    56    56    49    44    66    73    88    85    82    60    87    42    81    90  1161

 N  10.0     2     5     5     2     5     3     5     7     5    13     8    12     6     8     8     5    10   109

    15.0     3     1     1     5     1     1     0     0     2     2     2     1     1     1     0     4     4    29

 O  20.0     2     2     2     1     1     0     1     0     1     2     1     0     1     1     0     0     1    16

    25.0     1     3     3     0     0     0     1     0     0     0     0     2     1     1     0     0     0    12

 X  30.0     2     1     1     0     0     0     0     0     0     1     3     0     0     1     0     0     0     9

    40.0     0     0     0     0     0     0     1     0     1     0     0     1     0     2     0     0     0     5

    50.0     0     0     0     0     0     0     0     0     0     0     0     1     0     0     1     1     1     4

    60.0     0     0     1     0     0     0     1     0     0     0     0     0     1     1     0     0     0     4

    80.0     0     0     0     0     0     0     0     0     0     0     0     1     0     1     0     1     1     4

   100.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

   150.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

   200.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

   300.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

   500.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

  TOTALS    79    81    77    64    63    53    53    73    82   106    99   100    70   103    51    92   107

        0 WD3  VALUES LESS THAN   0.000          4761 WD3  VALUES LARGER THAN  180.0
        0 NOX  VALUES LESS THAN   0.000             0 NOX  VALUES LARGER THAN  500.0
```

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```
                    FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS MUNSEY NOX       WD3  RANGE  180.010 TO  360.0
                               FROM 76324 TO 77273                           NOX  RANGE    0.000 TO  500.0
                                                                             ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                    W  D  3

                 190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

          5.0     122   137   186   234   338   220   130   125   109    79    76    70    52    67    89    98    87    97  2316

   N     10.0      13    31    38    36    58    43    30    25    22    20    18    20    20    38    37    24    14    16   503

         15.0       4     3    10    13    23     9     3     9     5     3     4     8    19    23    19    15     7     3   180

   O     20.0       2     4     6     8    10     8     0     2     4     4     3     4     9    15     7     1     0     4    92

         25.0       1     1     4     2     3     1     1     3     2     2     2     8    14    12     3     2     3     0    64

   X     30.0       1     2     1     3     3     2     0     1     1     1     2     3    10    11     3     1     0     0    45

         40.0       2     2     4     7     3     1     2     3     1     0     2     3    15     9     5     4     0     0    63

         50.0       0     0     3     3     6     2     0     0     2     2     3     0    10    12     2     0     1     0    46

         60.0       0     1     1     1     5     1     1     2     1     1     4     1     4     7     2     2     0     0    34

         80.0       0     1     1     1     3     1     1     3     1     0     0     0     4     6     0     0     0     0    22

        100.0       1     0     3     2     2     2     0     2     0     2     0     0     0     4     0     1     0     0    19

        150.0       2     1     0     0     2     1     0     0     1     0     0     1     1     2     1     1     0     1    14

        200.0       0     1     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     2

        300.0       0     0     2     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     3

        500.0       0     2     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     2

       TOTALS     148   186   259   312   456   291   168   175   149   114   115   116   158   205   168   143   112   121

          1558 WD3  VALUES LESS THAN 180.010                 0 WD3  VALUES LARGER THAN  360.0
             0 NOX  VALUES LESS THAN   0.000                 0 NOX  VALUES LARGER THAN  500.0
```

```
              FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS KENTS  NOX      WD3  RANGE    0.000 TO  180.0
                            FROM 76324 TO 77273                       NOX  RANGE    0.000 TO  500.0
                                                                      ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                                     W  D  3

              10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0 100.0 110.0 120.0 130.0 150.0 160.0 170.0 180.0 TOTALS

        5.0     25    28    30    16    15     9     7    21    28    32    27    42    26    56    28    52    63   505

 N     10.0     26    35    23    22    11    18    15    24    15    16    19    27    20    18    10    13    20   332

       15.0     14    13    13    14    13     7     7    15    18    19    14     8     7    18     8    17    14   219

 O     20.0      8     9     7     4    12    11    15     8    14    23    17     8     5    16     8     7    20   192

       25.0      1     1     2     5     8    12     5     8     7     5     9     9     4     2     1     2     1    82

 X     30.0      0     0     1     2     0     1     1     1     0     1     1     1     0     0     0     3     1    13

       40.0      0     0     0     0     0     0     0     0     0     0     2     1     0     0     0     2     0     5

       50.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1     1

       60.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

       80.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      100.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      150.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      200.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      300.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

      500.0      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

     TOTALS     74    86    76    63    59    58    50    77    82    96    89    96    62   110    55    96   120

           0 WD3  VALUES LESS THAN   0.000         4761 WD3  VALUES LARGER THAN  180.0
           0 NOX  VALUES LESS THAN   0.000            0 NOX  VALUES LARGER THAN  500.0
```

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```
FREQUENCY DISTRIBUTION OF HOCKEY WD3 VS KENTS  NOX      WD3  RANGE  180.010 TO  360.0
                   FROM 76324 TO 77273                  NOX  RANGE    0.000 TO  500.0
                                                        ROW + COLUMN HEADINGS ARE HIGH ENDS OF INTERVALS
                          W  D  3

          190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 TOTALS

     5.0    62    68    69    62   102    88    44    33    35    25    35    40    81   150   109    55    40    36  1134

N   10.0    35    36    74    81   104    80    35    34    32    25    26    25    39    55    63    50    40    45   880

    15.0    32    45    62    80   140    91    31    41    40    25    31    23    27    43    29    28    22    22   812

O   20.0    24    29    62    86    95    62    34    45    31    22    16    25    26    38    31    20    16    15   677

    25.0     4    19    31    46    66    45    25    15    17    10    10     6    10    11     8     5     4     4   337

X   30.0     2     5    13    13    40    20    14     9    17     7     6     6    11    12     2     2     1     0   180

    40.0     5     8     6    11    23    11    17    13    10     8     3     9    12    15     3     1     0     1   156

    50.0     0     0     3     4     6     3     4     9     3     1     2     2     0     2     0     0     0     0    39

    60.0     0     0     0     3     4     5     5     3     1     0     0     0     0     0     0     1     0     0    22

    80.0     0     1     2     5     8     9     3     2     1     0     0     0     0     0     0     0     0     0    31

   100.0     0     0     0     0     1     0     2     0     0     0     0     0     0     0     0     0     0     0     3

   150.0     0     0     0     0     0     2     0     0     0     0     0     0     0     0     0     0     0     0     2

   200.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

   300.0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

   500.0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1

  TOTALS   165   211   323   391   589   417   214   204   187   123   129   136   206   326   245   172   123   123

      1568 WD3  VALUES LESS THAN 180.010              0 WD3  VALUES LARGER THAN  360.0
         0 NOX  VALUES LESS THAN   0.000              0 NOX  VALUES LARGER THAN  500.0
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